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Engineering Report

R 50-3-1

Final Report on Fabric Development

Contract No. as 52-2500

GENERAL DEVELOPMENT CORPORATION
Elkton, Maryland

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54AA 32

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. FABRIC DEVELOPMENT

2. INTRODUCTION

This project was undertaken for the purpose of developing a light weight, high strength airship envelope fabric.

The problem was attacked by first conducting a literature survey on textile materials in order to gather data on the mechanical behavior of textiles and to see what factors influence this behavior. In order to supplement the data from the survey, data was obtained from manufacturers of fibers and fabrics. The textile information gathered, led to the selection of nylon, dacron, and orlon since it was felt that these fibers had desirable characteristics and should be studied further. Various weaves were studied, some that looked promising were tested and the tests in Specification LTA-14a were used as screening tests for coated fabrics.

It was decided that a new method of coating should be developed in order that a more uniform coated fabric could be produced, and to reduce the weight of coating required. New techniques were developed in conjunction with the new method, in order to obtain optimum properties of adhesion and permeability at a minimum weight. The coating procedures developed in the laboratory were transferred to pilot plant equipment and finally to plant equipment.

This report is being submitted in accordance with Item 3 of Contract No as 52-250C and covers the work done to date.

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In order to compare the potential usefulness of different fibers, some criteria of behavior are needed. In his classical paper on fibers, H. Dewitt Smith* lists the basic mechanical properties of materials and the criterion of each as follows:

Quality	Service Rendered	Criterion
Strength	To carry a dead load	Ultimate strength
Stiffness **	To carry a load without (permanent) deformation	Modulus of elasticity
Elasticity	To undergo deformation and return to original shape upon cessation of deforming force	Elastic limit
Resilience	To absorb shock without permanent deformation	Modulus of resilience
Toughness	To endure large permanent deformation without rupture	Ultimate resilience

* Reference 8

** Smith's wording is misleading in light of the usual classical terminology for mechanical materials wherein recovery time is not important. Stiffness in mechanics is AE (area X Modulus of elasticity) or is defined as the force exerted by a tension member for a unit deformation having the dimension of force(F). In fiber studies terms such as stress and Modulus of elasticity, so common in mechanics, lose their importance due to creep - deformation recovery vs temperature and humidity influence.

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the original length, it has no dimensions.

Stiffness is measured by the slope of the elastic portion, Ox, of the stress-strain curve and equals Px/Ex. This is the elastic modulus expressed in grams per denier.

Average stiffness is the ratio of the breaking stress P to the breaking strain E, (as one hundredth of the percentage elongation) and is expressed in grams per denier.

Elastic deformation (or recovery) is the deformation which is completely recoverable after removal of the load, It is a combination of immediate and delayed recovery. It is expressed as a percentage of the total elongation.

Permanent set is that amount of elongation which is not recoverable even after an extended time. It is expressed as a percentage of the total elongation.

Toughness is measured by the area O-Y-U-E-O and expresses the total work required to rupture the material in grams per denier. The toughness index is the area O-U-E-O and is an approximation of the actual toughness. It generally is lower than the actual toughness because portions of the curve will be above the line O-U especially for higher elongation materials. It is determined simply as one half the product of the breaking stress P and the breaking strain E in terms of unit elongation (one hundredth of the percentage elongation.)

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3. Discussion

The coated fabrics used in the current airship envelopes consist of two ply cotton with a neoprene coating between plies, and on the outer side of the cloths. The composition of the cotton fabric is as follows:

Construction	Weight oz/sq. yd.
Aluminum coating	0.80
Neoprene	1.00
Basket weave, 2 x 2, bias (cotton)	4.50
Neoprene	5.50
Basket weave, 2 x 2, straight (cotton)	4.50
Neoprene	1.00
Total	17.30

The minimum specified tensile strength, by the cylinder burst test is 235 lbs/in. in the warp direction and 200 lbs/in. in the fill direction.

Although these fabrics have been satisfactory to date, it was felt that a considerable saving in weight could be obtained if high tenacity synthetic fibers could be used. Other properties that were sought were improved weathering characteristics, longer service life, less susceptibility to loss of life caused by mildew, humidity, and extreme temperature conditions.

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In a non-rigid airship all of the forces are resisted by the fabric in shear and tension since a fabric cannot assume loads in compression or bending. The rigidity of the envelope against compression loads results from the internal gas pressure. The shear and bending strengths of the envelope will determine the maximum operating pressure, which in turn determine the strength required in the envelope fabric.

Platt (Reference 13) has derived the following equation for calculating the total axial load from a yarn composed of multiple fibers;

$$P = 2\pi \int_{r=0}^{r} (fr) \left[\frac{r\, dr}{(1 + 4\pi^2 N^2 r^2)} \right]$$

where:

P = total axial yarn load

fr = stress intensity (force per unit area)

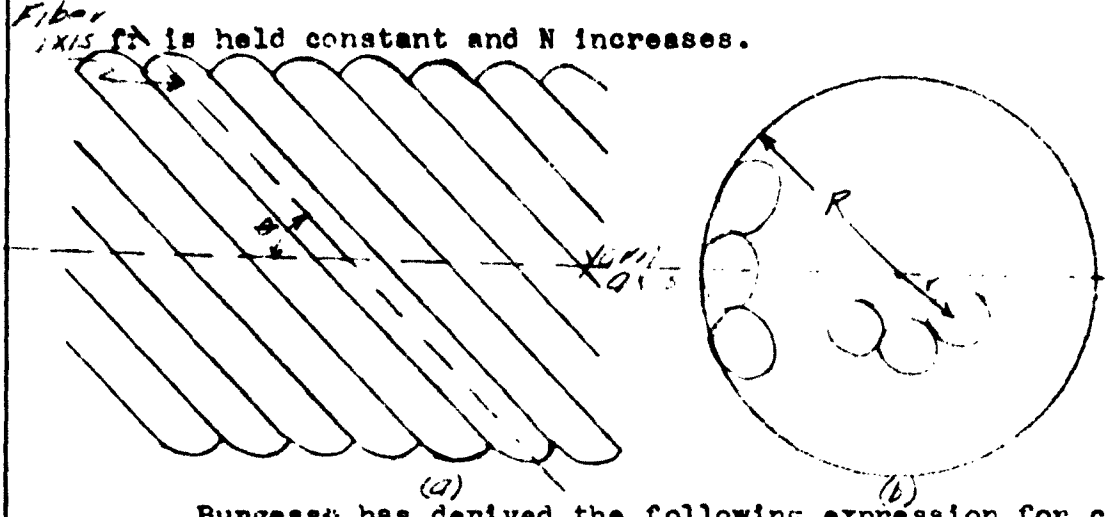
r = bounding radius of a layer of fibers (in.)

N = yarn twist (turns per inch)

This expression which covers only the geometric problem was derived without any consideration of the inherent properties of the fibers in the yarn and applies to continuous-filament yarns made of any fibers which satisfy the assumptions made by Platt.

In essence this equation shows that the higher the helix angle (θ) the greater the fiber tensile stresses when a given axial load acts on a continuous-filament yarn, since, if P is held constant, fr increases when N increases. Also with

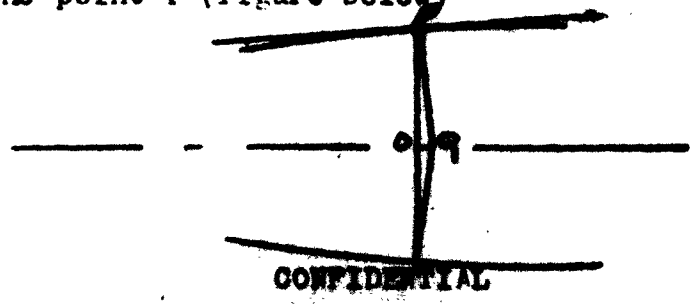
equal fiber stresses, the most highly twisted yarn will have the lowest axial yarn load, because P decreases as f_1 is held constant and N increases.



Burgess* has derived the following expression for calculating loads in an airship fabric

$$P = \frac{T_t}{R_t} + \frac{T_l}{R_l}$$

where the subscripts t and l indicate that the tension is transverse or longitudinal. However in calculating the strength of fabric required in an airship envelope, the last term of the above equation can be neglected because R_l is so much greater than R_t. By neglecting this term, the tapered portion of the envelope should be considered as consisting of a series of truncated cones. Thus, the transverse radius R_t, at the point P (figure below)



* Derivation shown in Appendix I

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is the length of line PQ drawn perpendicularly to the longitudinal tangent at P and intersecting the longitudinal axis at Q and not the line PO which is the radius of the transverse section at P.

In calculating shearing stresses in an airship envelope Burgess derived the following equation for longitudinal and transverse shear

$$f = \frac{F \sin \theta}{R \pi} \quad *$$

where

f = shear per unit of length of fabric

F = total transverse shear

R = radius of airship

θ = angle between vertical radius and radius to section under discussion.

The longitudinal and transverse shear expressions are the same and this agreement exists only when the cross-section is circular. This indicates that the ordinary bending moment formula is applicable only for circular cross sections, thus if the cross section is not circular, bending produces a distortion of cross section so that the assumptions made in the derivation of the expression are not filled.

* Derivation shown in Appendix I

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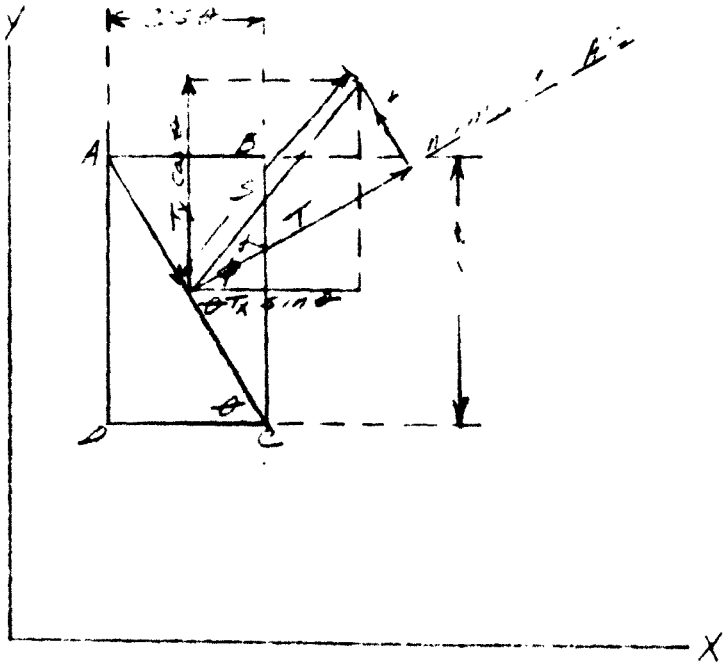
Burgess* also points out that the maximum intensity of stress m y not be in either the longitudinal or transverse direction and it may be desirable to know the direction and magnitude of the maximum and minimum tensions. The magnitude of the tension and shear in any direction may be determined by a geometrical analysis known as the "ellipse of stress". By using the figure below, an expfession is derived which is

$$\frac{S^2 \cos^2 \phi}{T_x^2} + \frac{S^2 \sin^2 \phi}{T_y^2} = 1$$ and this happens



Principal Stresses In a Non-rigid Airship Envelope

* Derivation shown in Appendix I

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to be an equation of an ellipse. S is the radius vector, and T_x and T_y are the axes. Thus the resultant stress S upon any line of unit length may be resolved into two components, a tension T normal to the line and a shear f parallel to the line. Then *

$$\alpha = \theta + \phi - 90^\circ$$

$$T = S \cos\alpha$$

$$f = S \sin\alpha$$

$$\tan\phi = \frac{T_y \cos\theta}{T_x \sin\theta}$$

An example showing how these equations are used is:

Given: T_x = 7 lbs/in., T_y = 11 lbs/in.

Find: S, T, and f upon a line inclined at 25° to OX

Solution:

$\theta = 25^\circ$; $\sin\theta = 0.4226$; $\cos\theta = 0.9063$

$$\tan\phi = \frac{(11)(0.9063)}{(7)(0.4226)} = 3.37$$

$\phi = 73^\circ\ 28'$; $\cos\phi = 0.2845$

$$S = \frac{Tx \sin\theta}{\cos\phi} = \frac{(7)(0.4226)}{(0.2845)} = 10.4 \text{ lbs/in.}$$

$\alpha = 25^\circ + 73^\circ\ 28' - 90^\circ = 8^\circ\ 28'$

$T = S \cos\alpha = 10.4\ (0.989) = 10.28$ lbs/in.

$f = S \sin\alpha = 10.4\ (0.1472) = 1.53$ lbs/in.

Only in the directions of the axes of the ellipse of stress is the resultant stress a pure tension without shear,

* Derivation in Appendix I

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for $\alpha = 0$ only when the stress is considered upon a line parallel to one of these axes. If the longitudinal and transverse tension and shear stresses are known, and the directions of the axes of the ellipse of stress is wanted, the following equation gives the magnitude of the maximum and minimum tensions in the fabric.

$$T_x' \text{ or } T_y' = \frac{T_x + T_y \pm \sqrt{(T_x + T_y)^2 - 4\,T_x\,T_y + 4\,f^2}}{2} \quad *$$

and solving for μ, one knows the amount of

$$\sin^2 \mu = \frac{T_x - T_x'}{T_x + T_y - 2\,T_x'} \quad *$$

rotation of T_x' and T_y' from the directions of T_x and T_y respectively.

Example:

Given: $T_x = 7$ lbs/in; $T_y = 11$ lbs/in; $f = 4$ lbs/in.

Find: direction and magnitude of the maximum and minimum tensions in the fabric (Burgess points out that these are directions of no shear)

Solution: The lengths of the axes of the ellipse of stress are equal to

$$\frac{7 + 11 \pm \sqrt{(7 + 11)^2 - (4)(7)(11) + 4\,(4)^2}}{2} = 9 \pm \frac{\sqrt{80}}{2} =$$

$$= 13.47 \text{ or } 4.53 \text{ lbs/in.}$$

* Derivation in Appendix I

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Letting the minor axis be denoted by X' (see fig. in appendix)

then:

$$\sin^2 \mu = \frac{7-4.53}{7 + 11 - 9.06} = 0.276$$

$$\sin \mu = 0.525; \quad \mu = 31^\circ \ 42'$$

So $T_{x'}$ and $T_{y'}$ are rotated 31° 42' counter clockwise from T_x and T_y respectively.

If the tension on an envelope falls below zero, folds begin to appear because fabric cannot sustain compression. Burgess points out that the limiting or critical value of f is $f = \sqrt{T_x T_y}$ *

By computing the required strength in an envelope fabric one can use the following equation, for a two ply fabric, for approximating the cloth strength:

$$T_R = T_1 + T_2 \sin 45^\circ$$

where T_R = strength required

T_1 = strength of straight ply cloth

T_2 = strength of bias ply cloth

The cloth strengths computed in this manner will be slightly higher than is actually needed, because it appears as though the neoprene coating may contribute to the strength of the plied fabric, which has not been accounted for in the above equation. In cotton two ply envelope fabrics it has been the practice to use the same fabric in both plies so the

* Derivation in Appendix I

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above equation then becomes

$$T_R = T_1 + T_1 \sin 45^\circ$$

or $$T_R = 1.707\ T_1$$

In the synthetic fabrics used in this program the bias ply cloth had approximately 50% of the tensile strength of the straight ply fabric, thus

$$T_R = T_1 + 0.5\ T_1 \sin 45^\circ$$

$$T_R = 1.354\ T_1$$

The tenacity of the fiber (gram/denier) is known and if it is multiplied by the yarn denier one knows the strength per yarn (gm/yarn).

In order to find the required yarns per inch in a cloth, T_1 or T_2 (lbs/in) is divided by the yarn strength (lbs/yarn).

Obviously, at best this is only an approximation and makes a good starting point for choosing fabrics for a specific strength requirement. Laboratory tests should follow and modifications made on the calculated cloth requirements.

Example: It is desired to produce a two ply dacron fabric having a strength of approximately 260 lbs/in. by the cylinder burst test. The dacron cloth shall be made of type 5100 yarns having a tenacity of 3 grams per denier.

Calculations

a. cloth strengths required

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$$T_R = 1.354\ T_1$$

$$T_1 = \frac{T_R}{1.354} = \frac{260}{1.354} = 192 \text{ lb/in.}$$

$$T_2 = 0.5\ T_1 = 96 \text{ lb/in.}$$

b. Required yarns/in. in the cloth:

using 220 denier in cloth 1

$$\text{Cloth 1} = \frac{(192)}{\frac{(220)\ (6)}{454}} = 66 \text{ yarns /inch}$$

using 70 denier in cloth 2

$$\text{Cloth 2} = \frac{96}{\frac{(70)(5)}{454}} = 104 \text{ yarns/inch}$$

Actually a straight ply consisting of a 2 x 2 basket weave, 220 denier, thread count of 67 x 67, tensile strength of 190 lbs/in. with a bias ply of 2 x 2 twill, 75 denier, thread count 72 x 67 and a tensile strength of 90 lb/in. gave a much higher strength than the 260 lb/in. used in the calculation.

Example: Calculate the required cloth strengths for a cotton two ply envelope fabric, using the same cloth in both plies, for cylinder burst strengths of 265 lbs/in. and 235 lbs/in.

a. for 265 lb/in. fabric

$$T_R = 1.707\ T_1$$

$$T_1 = 265/1.707 = 152 \text{ lb/in.}$$

b. for 235 lb/in. fabric

$$T_R = 1.707\ T_1$$

$$T_1 = 235/1.707 = 137 \text{ lb/in.}$$

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In actual practice a cloth with tensile strengths of 135 lb/in. and 125 lb/in. respectively are being used for the above two ply fabrics.

The current thought is that the ultimate desired airship fabric should consist of a single fabric constructed of three yarns, one straight and two bias yarns. This is a radical departure from the standard fabrics, whose yarns are woven at a 90° angle with respect to each other, because the geometry of this proposed fabric (fig. A) shows that it is composed of triangles and such a fabric can resist shear, thus eliminating bias plies.

Such a cloth would eliminate the hand biasing operation during the manufacturing of the coated fabric and the adhesion between plies requirement would vanish. The function of the coating would be solely to reduce permeability and to protect the cloth from the elements and suns rays.

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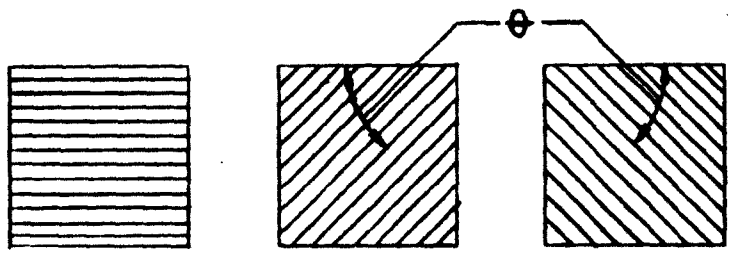
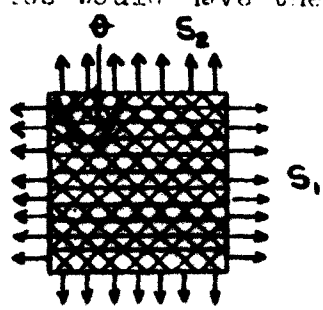
Preliminary discussions with possible manufacturers of equipment that could produce such a fabric are encouraging and they have stated that an engineering study is required before they could give a definite answer as to the possibility of weaving such a fabric.

Donnell (Reference 12) states that if unidirectional cloth could be used in an airship fabric and the warp ran in the direction shown below:



then the plied fabrics would have the following pattern.



If all three layers are of the same thickness, then the tensile strengths of the composite fabric in the directions shown would theoretically be:

$$S_1 = T\,(1 + 2\cos^2\theta) \qquad (a)$$

$$S_2 = T\,(2\sin^2\theta) \qquad (b)$$

where T is the tensile strength of one layer in the direction of its fibers. If $\theta = 30^\circ$ the above equations would reduce to

$$S_1 = S_2 = 1.5\ T \qquad (c)$$

and if $\theta = 45^\circ$ the results would be

$$S_1 = S_2 = 2T \qquad (d)$$

The actual needs of an airship fabric should lie between the limits of equations (c) and (d) and adequate shear strength should be provided by such a construction. It is assumed that this same theory would be valid for the three yarn cloth which was discussed above.

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4. SUMMARY OF WORK DONE

Initially a literature survey was made with special emphasis on the mechanical properties of fibers. This data was used to determine which fiber materials should be investigated. Only those fibers which have a high tenacity were considered suitable for further work. Nylon, Dacron and Orlon were chosen as representative materials of moderate elongation having differently shaped stress-strain curves. Fortisan was chosen both as a standard and as a high tenacity, low elongation fiber of the class which includes glass, ramie, flax and hemp. The cotton fabrics used in the three ply envelope fabric also were used as standards, since they have proven satisfactory in actual service.

Preliminary work on tensile and creep properties was carried out on a variety of fabrics. Orlon was eliminated from further study on the basis of a low strength-weight ratio, high creep and a low breaking time under load. Fortisan and cotton also break under static loads in a relatively short time. Dacron fabrics exhibited the least creep.

At this point, nylon, dacron 5500, and dacron 5100 fabrics were woven to specifications, arrived at through data obtained from the preliminary work, in order that a more intensive study could be made of their properties.

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Since fortisan and cotton envelope fabrics were used in actual service, they were tested in order that a basis for comparing test data could be formed.

4.1. Greated Fabrics

4.1.1 Effect of After Treatment

The nylon and dacron fabrics were obtained in the greige, scoured and heat set after scouring. This allowed the determination of the effects of after treatment on the fabrics.

In general, the greige fabrics have the lowest elongation, both at 20% of breaking load and at the break point. Scouring causes shrinkage which results in increased elongation. Heat setting, which was done with tension in the warp direction only resulted in further shrinkage and increased elongation.

The greige fabric shrinks the most during the drying and curing of the neoprene coating. This difficulty was overcome by heat setting the greige fabric while preventing shrinkage in the warp and fill direction. This method of treatment produced a fabric with the low elongation of the original greige fabric and one which was dimensionally stable to heat. Since a minimum elongation is desirable, it was felt that this last described method was the most advantageous for this particular use.

4.1.2 Elongation

Elongation of the fabrics at the breaking point is important as a measure of the ability to absorb energy. Fabrics with low ultimate elongations would rupture most easily when subjected to shock loads. Such a high rate of loading also decreases the ultimate elongation.

The elongation of the envelope in a relatively short period after filling with the gas determines the amount that the envelope will increase in size from the empty state.

A comparison of the elongation of various fabrics, at 20% breaking load, is listed below:

Fabric	Percent Elongation	
	20% load	Ultimate
Fortisan 373	0.9 x 1.1	7.1 x 7.4
R.R. Cotton	1.5 x 2.0	6.2 x 5.2
Dacron 15023 HB	3.3 x 2.7	28.5 x 25.6
Nylon 3142 HB	5.5 x 6.4	24.4 x 26.1

The table indicates that a fortisan envelope will probably increase in size the least amount, while nylon would increase in size more than the other fabrics.

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4.1.3 Strength - weight ratios

One method of comparing fabrics for use in airship envelopes is by their strength weight ratios. A fabric with a high ratio potentially will produce an envelope material with the lowest weight for a given strength. A comparison of the basket weave fabrics tested during this program is given below:

Fabric	Strength - weight ratio
RR Cotton	425 x 367
Dacron 15023 HB	720 x 738
Nylon 3142 HB	843 x 843
Fortisan 373	897 x 795

Fortisan 373 has a strength weight ratio slightly higher than nylon, and more than twice as high as the ratio for cotton. It must be pointed out that many other factors and fiber characteristics must be considered in selecting a new envelope fabric, because experience has shown that even though fortisan has a high strength weight ratio, it still was not suitable for an airship fabric, as will be shown throughout this report.

4.1.4 Tear

During this program it was felt that it would be desirable to develop a suitable tear test that would simulate conditions in an airship envelope

more closely than a tongue tear test. The new test is described in detail in the Second Quarterly Progress Report, PP 84-87. A comparison of tear strengths is given below.

Fabric	Tear, lbs.	Breaking strength lbs.
Fortisan 373	41.4 x 35.3	201.5 x 178.8
RR Cotton	53.2 x 56.4	137 x 130
Dacron 15023 HB	77.0 x 84.0	200 x 205
Nylon 3142 HB	81.0 x 82.0	187.2 x 187.2

Fortisan has the lowest tear strength, while nylon and dacron had the highest. The tear strength of fortisan is equal to 20% of its breaking strength. If therefore, fortisan is under a load of 20%, a small puncture of the fabric would result in complete tear. This is not the case with the other fabrics listed above.

4.1.5 Creep

Change in dimensions of fabrics under static load was studied intensively. Initial tests were at 20%, 40%, and 60% of the Scott Tester Breaking load.

Creep curves (creep vs. time) were plotted for the fabrics at the 20%, 40%, and 60% loads. Cotton and fortisan showed the least creep, with little change at higher loads. Nylon, dacron and orlon fabrics showed considerable creep, with the amount

increasing as the load was increased. The nylon fabric which had the least creep was the crepe fabric. This fact provided a clue for obtaining nylon fabrics with minimum creep.

Further tests on nylon and dacron fabrics in the crepe, scoured, and scoured and heat set treatments showed that the crepe fabrics had the least creep. Fabrics that were heat set in the crepe also exhibited relatively little creep. These latter materials offered the best hope for making nylon or dacron airship envelopes which would not continue to increase in size when inflated.

4.1.6 Change in Tensile Properties Under Load

It was felt that work should be done on following the changes in elongation and breaking strength with time under static loads. The elongation tended to decrease with time for all fabrics. Fortisan is the only fabric which lost tensile strength; the tensile strength of the other fabrics did not change much.

The time for a fabric to fail under load was also observed. At 40% and 60% of the breaking load, cotton, fortisan and orlon failed within relatively short periods of time, while dacron took the longest time to fail. Even at 20% of breaking load, the fortisan fabrics were the first ones to fail.

41.7 Effects of Heat

The fabrics were subjected to elevated temperatures for a number of different periods of time, to determine possible effects of curing conditions.

Dacron showed little change in strength even after heating at 300° F for 30 minutes, the other fabrics showed some decrease in strength after heating at 300°F for 30 minutes. The greige heat set fabrics were better than the other methods of treatment.

Heating at elevated temperatures also affected the tear strength. Dacron was the best in retaining its strength; nylon tear strength decreased rapidly above 300°F; and fortisan 373 lost tear strength at a temperature as low as 200°F.

The results are summarized in the table below. Since the curing conditions required for the neoprene coating are 30 minutes at 300°F, the results for these conditions are given:

Effect of Heating at 300°F for 30 Min.

Fabric	Tensile Strength, Lbs/in.	Elongation,%	Tear Strength, Lbs.
RR Cotton	137 x 130	6.2 x 5.2	53 x 56
heated	126 x 112	4.8 x 5.3	31 x 57
Fortisan 373	202 x 179	7.1 x 7.4	41 x 35
heated	186 x 176	6.2 x 6.8	22 x 18
Nylon 3142 HB	187 x 187	24.4 x 26.1	81 x 82
heated	181 x 201	21.8 x 24.1	77 x 80
Decron 1503 HB	200 x 205	28.5 x 25.6	77 x 84
heated	205 x 209	26.3 x 27.8	72 x 78

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Elkton, Maryland

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	COTTON
	3.3 to 3.37
	3 - 7
	@ 2

4.1.9 COMPARISON OF TEXTILE

PROPERTY		SAPONIFIED ACETATE	
Tensile Strength (g.p.d.)	std	7.0	
	wet	6.0	
Elongation (%)	std	6.0 - 6.5	
	wet		
Elastic Recovery (%)		100 @ 20%	
		90 @ 40	
Tensile Strength (p.s.i.)		136,000	
Average Stiffness (g.p.d.)		116.6	
Average toughness $\frac{g.cm}{d.cm}$		0.21	
Specific Gravity		1.3	
Regain (Adsorption) (65% r.h.)		10.5	
Water Absorbency		20 @ 95 r.h.	
Effect of heat		More nearly like viscose rayon i.e. loses strength above 300°F, decomposes 350-400°F does not melt, burns rapidly.	elts at 4 at 300°F
Effect of age		Slight on tensile - none on color.	Virtually
Effect of sunlight		Slight on tensile none on color	Loses stre exposure,
Effect of acids		Concentrated solutions of strong acids decompose.	Boiling in causes dis with at le position b HCl, H_2SO_4
Effect of alkalis		Strong alkalis saponify into regenerated cellulose	Substantia
Effect of other chemicals		Attacked by strong oxidizing agents, not damaged by hypochlorite or peroxide bleaching solutions	Generally
		Terylene not affected	Generally

4.1.9 [illegible]

PROPERTY		[illegible]	[illegible]	DACRON [1]	COTTON
Tensile Strength (g.p.d.)	std	7.0	6.4 - 7.5	4.0 - 5.0	3.3 to 5.37
	wet	6.3	5.7 - 6.6	4.0 - 5.0	
Elongation (%)	std	6.0 - 8.5	17 - 19	20 - 30	3 - 7
	wet		20 - 22	20 - 30	
Elastic Recovery (%)		100 @ 2%	100 @ 4	90 - 100 @ 4	74 @ 2%
		90 @ 4%		80 - 90 @ 8	45 @ 5%
Tensile Strength (p.s.i.)		136,000	85,000 to 109,000	71,000 to 88,000	44,000 to 109,000
Average Stiffness (g.p.d.)		116.6	39	13 - 25	57 - 60
Average toughness g.cm / d.cm		0.21		0.49 - 0.63	0.15
Specific Gravity		1.5	1.14	1.38	1.54
Regain (Absorption) (65% r.h.)		10.5	3.8	0.4	7.0%
Water Absorbency		20 @ 95% r.h.	6.1 @ 95% r.h.	0.5 @ 95% r.h.	24 - 27
Effect of heat		Wore nearly like viscose rayon i.e. loses strength above 300°F, decomposes 390-400°F does not melt, burns readily.	Melts at 482°F, yellows slightly at 300°F when held for 5 hrs.	Melts at 480°F	Highly resistant to degradation. Yellows at 248°F after 5 hrs, decomposes at 302°F
Effect of age		Slight on tensile - none on color.	Virtually none	Virtually none	Little or none
Effect of sunlight		Slight on tensile none on color	Loses strength on prolonged exposure, no discoloration.	Loses strength on prolonged exposure. No discoloration. much more resistant behind glass than in direct sunlight.	Loss of strength, tendency to yellowing.
Effect of acids		Concentrated solutions of strong acids decompose.	Boiling in 5% HCl ultimately causes disintegration, dissolves with at least partial decomposition by cold conc.sol. of HCl, H_2SO_4, HNO_3.	Good resistance to most mineral acids. Dissolves with at least partial decomposition by conc.sol. of sulphuric acids.	Disintegrated by hot dilute acids or cold conc. acids. Unaffected by cold weak acids.
Effect of alkalis		Strong alkalis saponify into regenerated cellulose	Substantially inert	Good resistance to weak alkalis and moderate resistance at room temps. Disintegrates by strong alkalis at boiling temps.	Swelling in caustics but no damage
Effect of other chemicals		Attacked by strong oxidizing agents, not damaged by hyperchlorite or peroxide bleaching solutions	Generally good resistance	Generally good resistance, excellent resistance to bleach and other oxidizing agents.	Bleached by hypochlorites, oxidizes into oxycellulose.
Effect of organic solvents		Fortisan not affected	Generally insoluble in some	Generally insoluble in some	Resistant

Effect of acids	Concentrated solutions of strong acids decompose.	Boiling in 5% HCl ultimately causes disintegration, dissolves with at least partial decomposition by cold conc.sol. of HCl, H_2SO_4, HNO_3.	Good resistance to most mineral acids. Dissolves with at least partial decomposition by conc.sol. of sulphuric acids.	Disintegrated by hot dilute acids or cold conc. acids. Unaffected by cold weak acids.
Effect of alkalis	Strong alkalis saponify into regenerated cellulose	Substantially inert	Good resistance to weak alkalis and moderate resistance at room temps. Disintegrates by strong alkalis at boiling temps.	Swelling in caustics but no damage
Effect of other chemicals	Attacked by strong oxidizing agents, not damaged by hyperchlorite or peroxide bleaching solutions	Generally good resistance	Generally good resistance, excellent resistance to bleach and other oxidizing agents.	Bleached by hypochlorites, oxidizes into oxycellulose.
Effect of organic solvents	Fortisan not affected	Generally insoluble in some phenolic compounds and in conc. formic acid.	Generally insoluble in some phenolic compounds.	Resistant
Resistance of moths	Wholly	Wholly	Wholly	Unaffected
Resistance to mildew	Highly discoloration only	Wholly	Wholly	Poor unless bleached
Dielectric strength	5,000 volts per mil	1,000 volts per mil (film)	3,000 volts per mil (film)	
Typical uses	Used for light weight fabrics for coating, laces, threads, general reinforcing, industrial belting, hose, military uses.	Hosiery, satins, taffetas, marquisettes, ribbons, tapes, webbing, tricot underwear, and gloves, laces, nets, threads, ropes, fish lines, tire cords, filter cloths, net) cloth.	Suitings, shirts, blouses, curtains, sweaters, socks, sewing thread, ropes, industrial beltings, fire hose.	Underwear, outerwear, industrial fabrics, household fabrics, guaze, upholstery, knit goods.
Method of manufacture	Cotton linters or wood pulp are acetylated with acetate anhydride to form cellulose acetate which, dissolved in acetone, is extruded into warm air to form filaments. High elongation acetate is produced by a modification of the process; saponified acetate, by a special stretching and saponification process.	Can be made in a number of ways such as the reaction between a diamine (for example hexamethyl di mine) and a dicarboxylic acid like adipic acid. In the manufacture of yarn, the polyomide is melted, extruded through a spinneret, and stretched.	Produced from a chemical composition of ethylene glycol and terephthalic acid. In the manufacture of yarn, the polyester is melted, extruded through a spinneret and stretched	
Identification	Melts before burning, forms hard black ball on tip; soluble in acetone; insoluble in methyl chloride. Saponified cross section similar to acetate, but tests like regenerated cellulose.	Melts before burning; insoluble in acetone or boiling Na OH solutions; solutions; soluble in conc. formic acid and xylenol.	Melts before burning. Soluble in hot metacresol, but not soluble in acetone or conc. formic acid.	Burns rapidly, leaves fine gray ash and no bead. Longitudinal appearance is flat and ribbon like with convolutions. Dissolves in 80% cold sulphuric acid.

1 high tenacity dacron has a tensile strength of approx 9.0 g.p.d.
* Ref 9 , Textile World Synthetic Fiber Table, 1951 Edition

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4.2. Coated Fabrics

4.2.1 Effects of Coating Method and Coating Weight on Tensile and Tear

Data on the effects of coating single plies of fabric was determined. The tensile strength varies with the amount of coating applied and with the method of application. In general, the greater the degree of penetration of the coating, the greater the increase in tensile strength with increase in weight. This is especially so for the cotton fabrics. Dortisan, on the other hand, decreases in strength with increases in the coating weight.

The tear strength decreases as the coating weight is increased. The degree of penetration of the coating has little effect. Cotton and nylon basket weave lost about one half of their original tear strength.

4.2.2 Adhesion

Work on adhesion showed that degree of penetration of coating, amount of coating, and distribution of the coating on the two fabric surfaces all affect adhesion. The penetration of the coating and the amount of coating applied are related. A heavy coating with considerable penetration may give poorer adhesion than a lighter coat with optimum penetration. Too little penetration also

results in low adhesion for a given weight of coating. It is important to obtain maximum adhesion at the minimum coating weight so the final envelope fabric can be kept low.

It was found that maximum adhesion is attained when the coating weights on the two surfaces to be plied together are equal.

Adhesion of a neoprene coating to nylon and dacron fabrics is poor. In order to improve the adhesion the nylon and dacron fabrics were primed with a neoprene cement containing a diisocyanate. Adhesions of over 10 lbs. per inch are readily attained by this technique.

4.2.3 Permeability

The permeability of the coated fabric also is related to the amount of coating and the degree of penetration.

Increased amounts of coating decrease the permeability, as can be expected. If the coating is on the surface of the fabric, permeability is the same as that of an unsupported film. As penetration increases for a fixed coating weight, permeability decreases. This phenomenon, which is called "fabric help" permits the use of less weight of coating to attain a given permenability.

4.2.4 Rotoflex Tests

The rotoflex tests were conducted in accordance with Specification LTA-14a, which consisted of 20 cycles in each of four directions on the fabric under an 880 gram load at 180 cycles per minute. These conditions were extended to obtain a better understanding of the changes which may occur during the test. Most of the tests were carried out at 200 cycles per minute using 880 gram or 3,000 gram loads. The changes in tensile strength and permeability with time rotoflexed were followed.

The 3 ply cotton envelope fabric was studied first. After seven seconds of rotoflexing, the time required for twenty flexes, there was little change. A longer time, however, showed a drop in tensile strength to 81% of the original value after 10 minutes rotoflexing and to 61% after one hour. The following fabrics were rotoflexed for tensile strength is as follows:

Plied fabric	% decrease in strength 1 minute	10 minutes
3 ply cotton	0.0	19.0
3 ply fortisan	47.5	69.6
2 ply nylon	0.5	3.5
2 ply dacron	0.6	14.6

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These results probably are a measure of fatigue of the various fiber materials. They show that Fortisan fabrics would fail under load when subjected to cycles of stress more readily than the other fabrics.

Changes in permeability were more complex. These were found to be related to adhesion and fabric help. Poor adhesion allows the film to separate from the fabric. If fabric help originally is low, then there is little change in permeability which remains that of a free film. If fabric help is high, the film separates from the yarns and develops thin spots. Permeability then increases after rotoflexing. Optimum conditions are high adhesion and high fabric help ratio, which produces low permeability at low coating weights with little increase in permeability after rotoflexing. Thus a balance of properties is required because adhesion first increases and then decreases as fabric help ratio increases. It is necessary to find the minimum weight of coating and the maximum fabric help ratio which will give the desired adhesion. For the nylon and dacron fabrics the minimum coating weight is about [illegible] gm/sq yd. between plies (exclusive of adhesive) and a fabric

help ratio of 3.5 to 4.0. This produces adhesions of 10 lbs/in. or more with the proper adhesive coat.

4.2.5 Latex Seal Coats

A major problem in obtaining minimum coating weights with low permeability was controlled penetration of the coating into the fabric. This is particularly difficult to do when knife coating open weave fabrics such as basket weave materials tested in this program and generally it is found that penetration is excessive. One approach studied was to seal the fabric with a latex coating and then apply solvent coats. The solvent coat did not attack the latex coat as it would a solvent neoprene seal coat and penetration was prevented.

Unfortunately, permeability increased after rotoflexing samples prepared by this method. Results were inconsistent, so work with latex seal coats was dropped in favor of a film transfer coating procedure.

4.2.6 Preparation of Plied Fabric

Laboratory investigation of methods of coating and amounts of coating to obtain required properties led to a procedure which was eventually tried on plant equipment. It was necessary to modify the

laboratory procedures when pilot plant runs were made. The method described below was adopted as the best of those tried to date.

The twill and basket weave fabrics were coated on both sides with the adhesive composition. Neoprene compound was applied and the twill was placed on a 45° bias. A black neoprene coating was applied to the inside surface and an aluminum coat to the outside surface. The material was heated in a festoon oven to cure the coating composition.

The neoprene coating on the inside surface was necessary to improve abrasion resistance.

4.2.7 Aluminum Coatings.

Aluminum coatings were formulated with various carriers. Weatherometer tests showed that their weathering resistance was good, however it was felt that actual exposure test data was more desirable.

Seam adhesion tests (without buffing the aluminum coating) showed that the neoprene coating gave adhesions in excess of 10 lb/in., however aluminum coatings having carriers other than neoprene did not have as good seam adhesions. Seam

tensile tests also showed the neoprene coating to be the best, since the fabric failed before the seam. Therefore it is believed that a desirable seam could be made that would not require the buffing off of the aluminum coating as is the current practice. This eliminates the possibility of damage always present during removal by abrasion (buffing).

4.2.8 Comparison of Properties of Aluminum Coated Fabrics

The table below shows a comparison of some properties of 3 ply cotton envelope fabric and of the nylon and dacron envelope fabrics developed under this contract.

	3 ply cotton	Nylon	Dacron
Weight (oz/sq.yd)	19.5 ± 0.5	12.0±0.5	13.5±0.5
Tensile strength (lbs/in)	190 x	190 x 101	211x218
Tear strength (lbs)	93 x	124x132	139x150
Adhesion between plies (lb/in)	>10	>10	>10
Permeability (l/M^2/24 hrs)			
initial	<3	<3	<3
after rotoflex	<3	<3	<3
Strength-weight ratio	152	250	237
Yards to break* (tensile strength)	5610	9120	9003
Creep	least	most	med.
Loss in tensile under load	most	med.	least
Weather resistance	lowest	med.	best

* Minimum length of material one yard wide which will break when suspended by one end.

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	3 Ply Cotton	Nylon	Dacron
Cylinder burst strength	260	312	349
Strength-weight ratio based on cylinder burst test	213	416	413
Yards to break (cyl.burst test)	6300	14,900	14,900

4.2.9 Properties of Fortisan Fabrics

Samples of Fortisan envelope fabrics were tested. These samples and their composition are:

R-27-F-120-5 Three basket weave fabrics, center ply on 45° bias. Wt. 16.63 oz./sq.yd.

R-27-F-111-5 One basket weave fabric and two twills on a bias. Wt. 15.20 oz./sq.yd.

R-27-F-116-5 Two basket weave fabrics with a twill on a bias between them. Wt. 16.83 oz./sq. yd.

Y-502A9 - M ship fabric. Plain end fabric, no aluminum coat. Three twills with center fabric on bias. Wt. 15.19 oz/sq. yd.

Y-502A12 - F ship fabric. Three twills with two outside fabrics on a bias. Wt. 13.93 oz./sq.yd.

The properties of these fabrics are given in the following table. Breakdown in permeability and tensile strength is shown in Figures A and B compared to Dacron fabrics. The R-27-F-111-5 fabric increases considerably in permeability after Rotoflexing. All the Fortisan fabrics

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decrease in tensile strength to less than one-half the original value after 2-3 minutes Rotoflexing under a 3000 gram load.

PROPERTIES OF FORTISAN ENVELOPE FABRICS

Fabric	Adhesion, Lbs./In. back-center	Adhesion, Lbs./In. center-front	Tensile Strength Lbs./In. Warp	Tensile Strength Lbs./In. Fill	Permeability $L/M^2/24$ hrs. (2 samples)*
R-27-F-120-5	5.0	6.3	over 300	293	2.5, 2.0
R-27-F-118-5	5.9	6.0	276	over300	4.0, 4.0
R-27-F-111-5	4.0	5.2	204	170	1.4, 1.2
Y-502A9	7.3	7.9	over 300	276	2.4, 2.7
Y-502A12	6.0	7.0	178	145	1.6, 1.2

* 880 gm load

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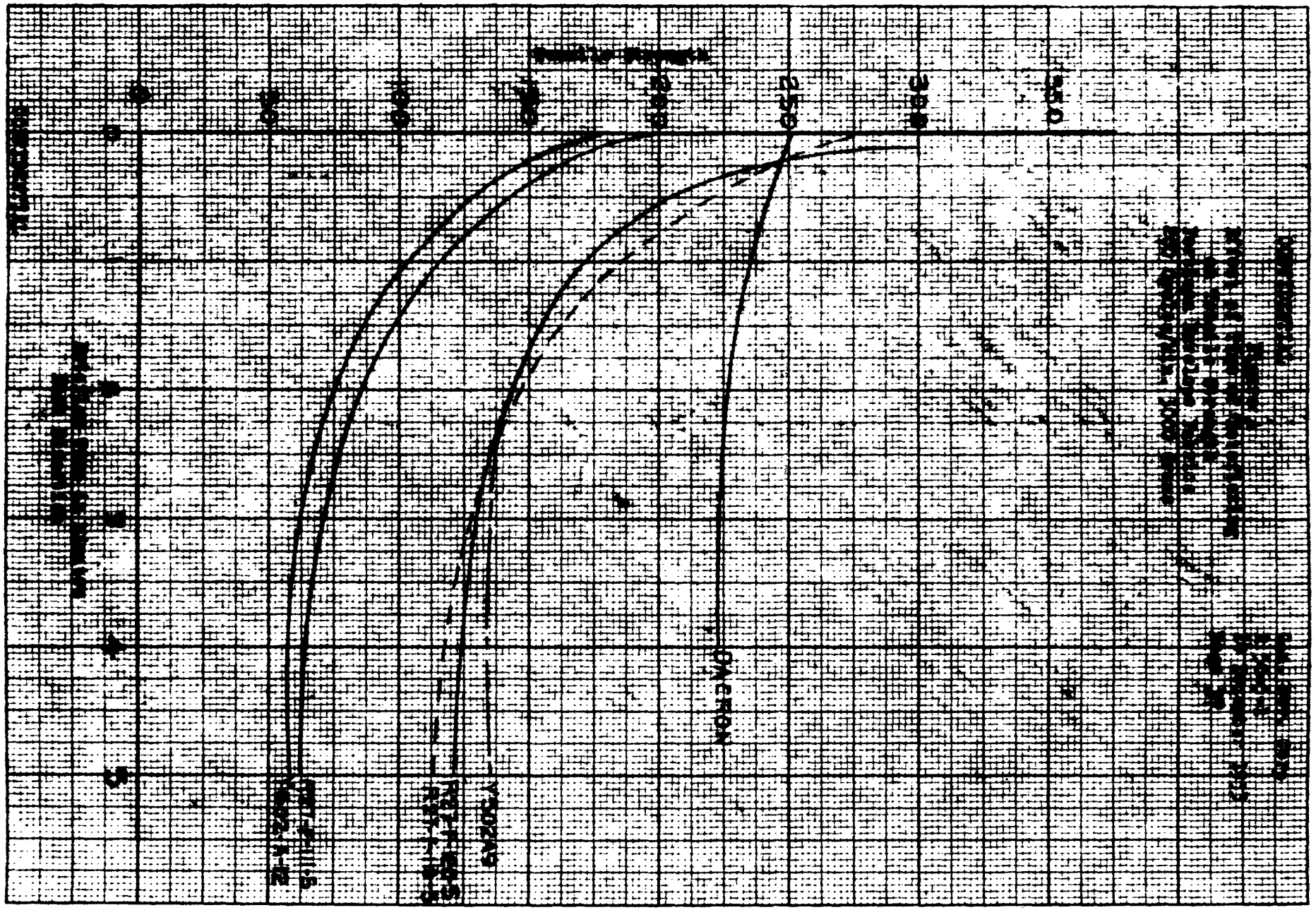

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Figure 4
Effect of Time of Rotoflexing
on Tensile Strength
Fortiman Envelope Fabrics
200 Cycles/Min. 3000 Grams

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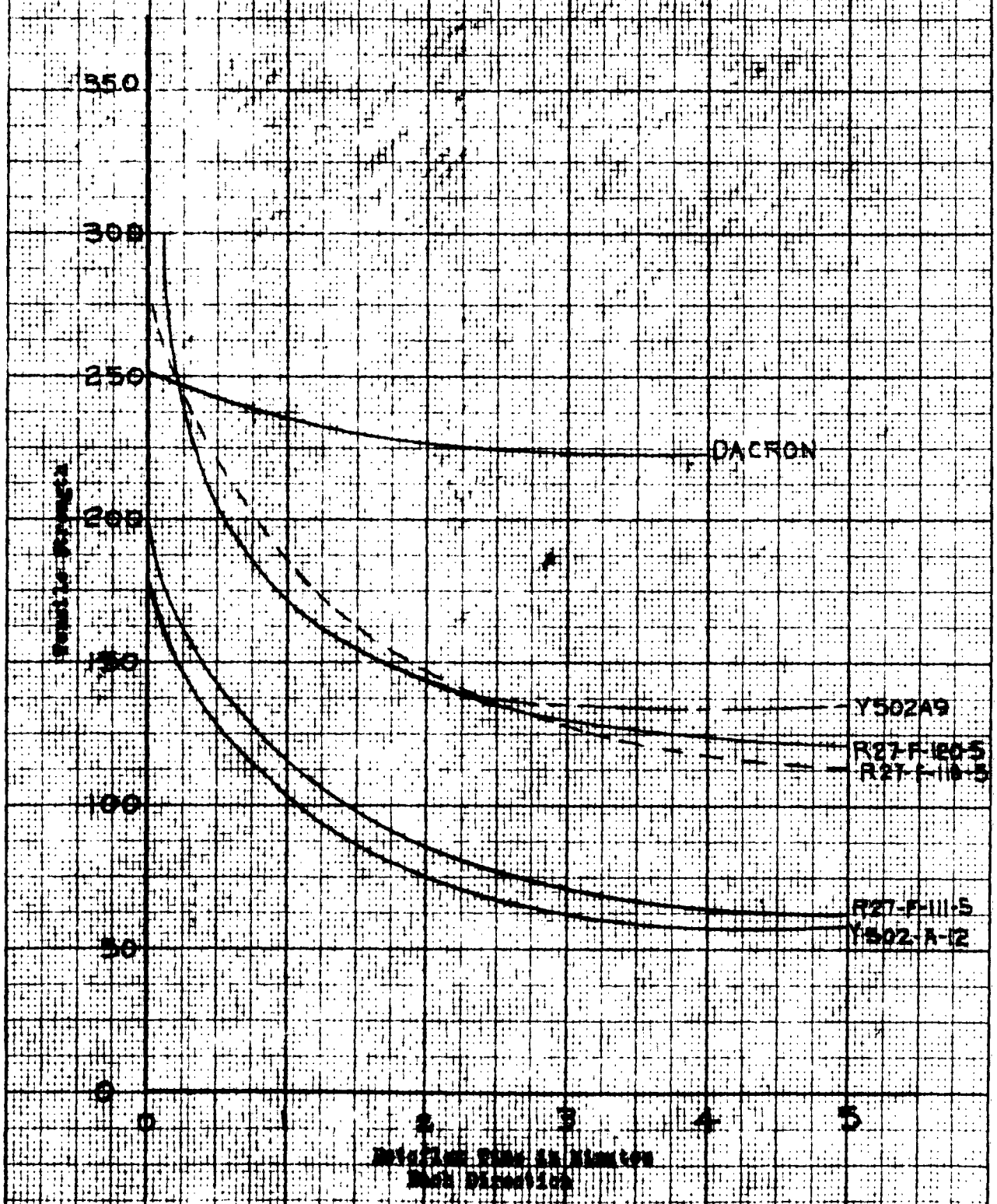

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FIGURE 3
Effect of Time of Autoflexing
on Permeability
Fortisan Envelope Fabric

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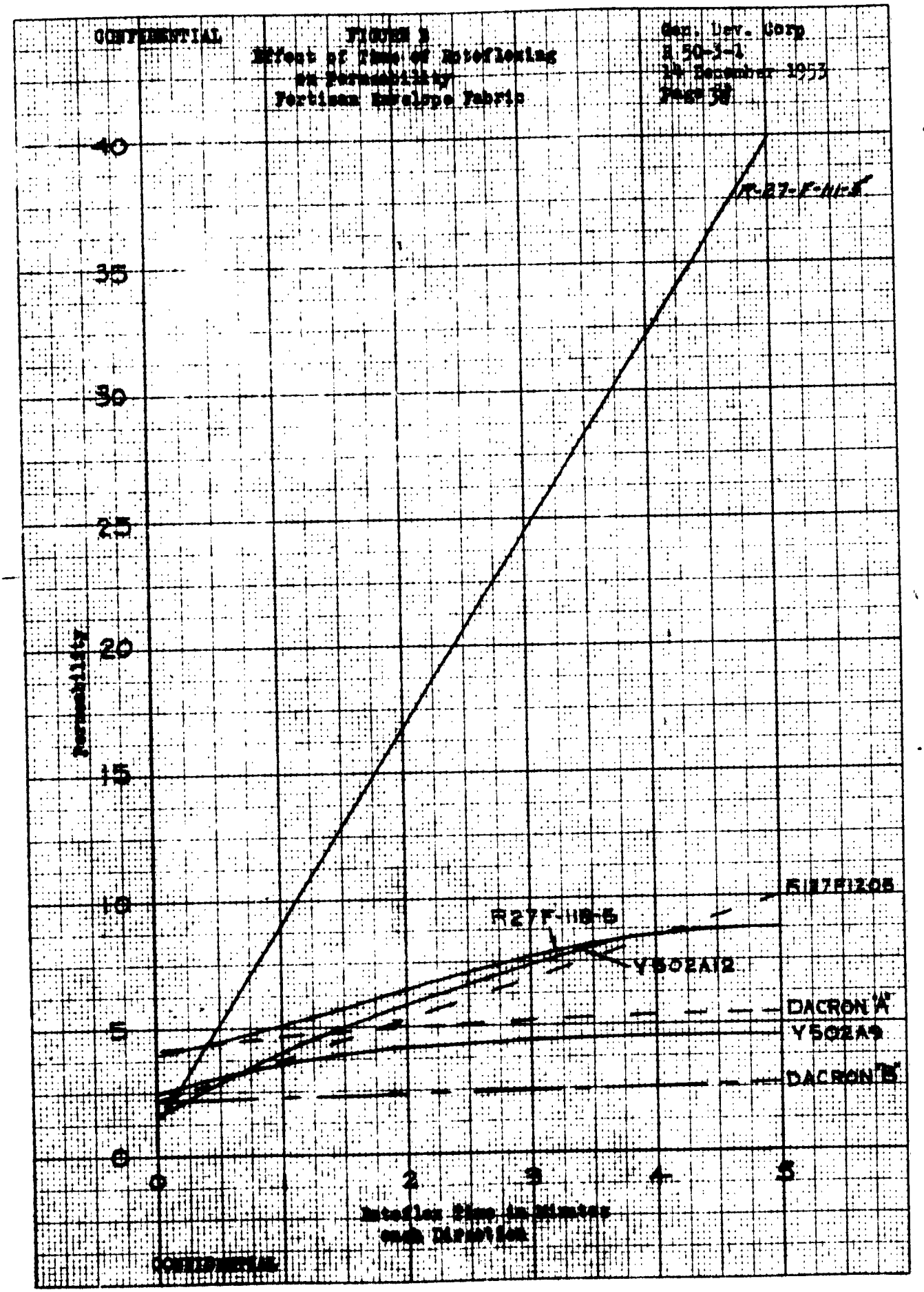

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4.3 Plant runs

4.3.1 Construction of plied fabrics and test results

A number of small plant runs were made so that the techniques developed in the laboratory and in the pilot plant could be tested on plant equipment. Most of the first runs were unsuccessful, however by making slight changes the initial difficulties were overcome. The fabrics from the most successful runs (6,7(1), 7(2), and 9) are listed below:

Plant Run #6

2 ply nylon with a black neoprene top coat

A. Construction		Wt.(oz/sq yd)
neoprene on basket weave		0.45
adhesive on basket weave		1.02
basket weave fabric		3.43
neoprene between plies		1.98 - 2.98
twill fabric		2.57
adhesive on twill		0.86
neoprene on twill		1.20
	Total	11.51-12.51 (12.0 - 0.5)

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b. Test results

adhesion between plies	13.0 lbs/in.
tensile strength	190 x 191 lbs.
elongation, ultimate	21.1 x 23.9%
elongation at 20% breaking load	3.3 x 4.3%
tear strength	124 x 132 lbs.

permeability ($l/M^2/24$ hrs)	initial	7 sec. rotoflex 880 gm load
10.95 oz/sq.yd.	6.0	not determined
11.20 oz/sq.yd.	6.0	not determined
11.88 oz/sq.yd.	4.4	not determined

strength weight ratio(based on highest weight) 260

Plant Run #7 (2)

2 ply nylon with air dry aluminum coat.

a. This fabric has the same composition as the one above except for an additional coat of 0.45 oz/sq.yd. of aluminum composition.

b. Test results

permeability	initial	7 sec. rotoflex 880 gm load
12.08 oz/sq.yd.	3.4	4.1
12.13 oz/sq.yd.	2.7	3.0
11.40 oz/sq.yd.	7.6	12.0

The higher total weights of the first two samples accounts for the lower permeability.

strength-weight ratio (based on highest weight) 251

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Plant Run #9

2 ply dacron fabric with a cured neoprene aluminum coat

a. Construction	Weight (oz/sq.yd)
neoprene on basket weave	0.37
adhesive on basket weave	1.15
basket weave fabric	4.55
neoprene between plies	2.24-3.58
twill fabric	3.00
adhesive on twill	1.00
neoprene - aluminum	0.62
	12.93 - 14.27
	(13.6 ± 0.67)

b. Test results

adhesion between plies	11.3 lbs/in.
tensile strength	211.2 x 218.0 lbs/in.
elongation, ultimate	25.1 x 27.2%
elongation, at 20% breaking load	1.2 x 2.1%
tear	139 x 150 lbs.

permeability	initial	7 sec. rotoflex 880 gm. load
12.93 oz/sq.yd.	3.8	4.0
14.10 oz/sq.yd.	3.6	3.7
14.20 oz/sq.yd.	3.2	3.8
14.27 oz/sq.yd.	3.6	3.5

Strength weight ratio (based on highest weight) 237

Cylinder burst strength 349 x 359 lbs/in.

Strength weight ratio (Cyl. burst) 391

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4.3.2 Effects of curing schedules

Samples of plant run #6 nylon fabric were cured at different temperatures and times, mainly to determine changes in creep. Tensile strength changed as shown below:

Temp. °F	Time, hrs.	Tensile Strength, lbs/in.
300	0.5	190
285	1	190
270	2	181
255	4	178

The tensile strength decreased as the curing time was increased, even though the temperature was lower. However, creep tests on the above samples show that the one cured at 255°F had the least creep. These tests are still being continued.

The fabrics from plant runs #8 (nylon) and #9 (dacron) were cured at 255°F for 2.5 hours. Creep samples show no change in length after being under load for a period of 20 days. These tests are being continued.

4.3.3 Aluminum Coats

Three different aluminum coatings were applied to nylon and dacron envelope fabrics. These coatings are based upon Acryloid C-10, Neoprene, and Hypelon. Samples were placed in a Weather-O-meter and will be inspected periodically.

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Adhesion of these coatings was determined. One object in formulation was to prepare a coating which gave good protection and which would not have to be removed for seaming. The results were as follows:

Coating	Primer	Adhesion, lbs/in.
Neoprene	none	13
	yes	17
Acryloid C-10	none	3
	yes	10
Hypalon	none	5
	yes	9

The neoprene coating gives the best adhesion even without the use of an aluminum primer adhesive.

Fabric was coated in the plant with the neoprene coating and with the acryloid C-10 coating. The acryloid coating was included as an air drying material. The neoprene coating was cured. The results are tabulated below:

Fabric	Alum. Coating	Seam Adhesion lb/in.	Seam tensile lb/in.
nylon	acryloid	1.5	161 (seam failed)
nylon	neoprene	8.7	192 (fabric broke)
dacron	neoprene	10.7	217 (fabric broke)

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These results indicate that a neoprene aluminum coating can be made that will give adequate seam adhesion, and eliminates the buffing off of the aluminum coating at the seams as is the current practice.

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5.0 Detail discussion of experimental work

5.1 Literature Review and Discussion

The mechanical behavior of a fiber does not follow the pattern of normal structural materials such as wood, steel or concrete. Fibers differ in their performance from these materials in that they exhibit delayed elastic and plastic effects.

One means of representation of these effects by a mechanical model is the combination of springs and dash-pots known as a Maxwell unit. The general behavior of such units upon the application of stress depends upon the force necessary to extend the spring, the viscosity of the dash-pot and how the flow properties of the dash pot are affected by rate of application of the load. In general flow is non-Newtonian.

Normally in the application of stress to a fiber a combination of elastic and plastic effects takes place at the same time. This corresponds to the simultaneous extension of the spring and flow in the dash pot. Upon release of stress, there occurs an immediate elastic recovery, a delayed elastic recovery, and reveals a permanent set. The degree to which each occurs depends upon the fiber material and upon the extent of elongation.

There is a large body of literature on this and other theories of plastic behavior of high polymers, including fibers (Ref. 1 to 8)*. This literature is concerned with

*Bibliography, Appendix II

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the mathematical interpretation of elastic behavior, plastic flow and stress relaxation of polymers.

It is believed that a review of this field, and the application of such knowledge to the problems of analysing the properties of an airship envelope fabric, constitutes a separate phase of the problem outside the scope of this project and should be undertaken as such. For this reason, no review or discussion of this portion of the literature will be presented.

5.1.1 Fundamental properties of fibers and yarns

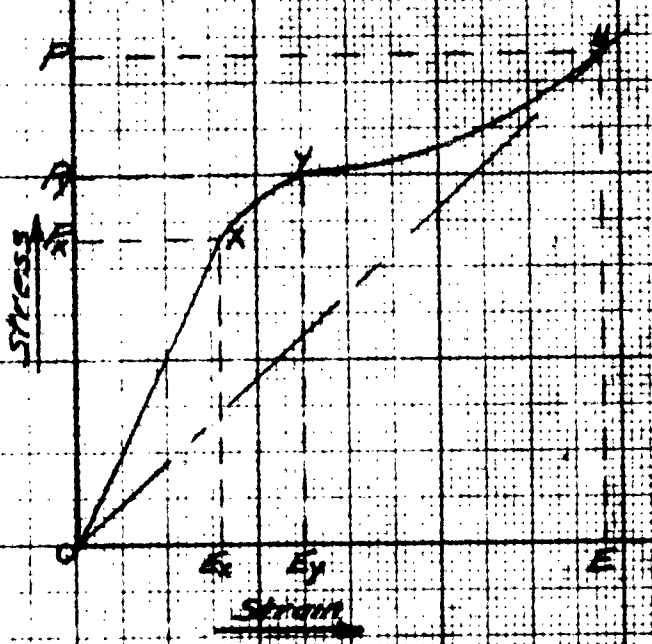
In order to compare the potential usefulness of different fibers, some criteria of behavior are needed. In his classical paper, H. DeWitt Smith (9)* lists the basic mechanical properties of materials and the criterion of each as follows:

Quality	Service Rendered	Criterion
Strength	To carry a dead load	Ultimate strength
Stiffness	To carry a load without deformation	Modulus of elasticity
Elasticity	To undergo deformation and return to original shape upon cessation of deforming force.	Elastic limit
Resilience	To absorb shock without permanent deformation	Modulus of resilience
Toughness	To endure large permanent deformation without rupture	Ultimate resilience

These properties and most others given below are best obtained from load-elongation (stress-strain) curves. On such curve, with its characteristic portions indicated is shown in Figure 1.

FIG. 1

A TYPICAL STRESS-STRAIN CURVE



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Stress is the applied load in grams per denier.

Denier is a unit of linear density in grams per 9000 meters.

Grex is a unit of linear density in grams per 10,000 meters.

Strength is measured by the breaking stress P in grams per denier. This is the **tenacity**. **Tensile strength** is expressed in pounds per square inch to rupture and does not involve densities.

Strain is the resultant of applied stress measured by the elongation.

Elongation - total or ultimate elongation is the elongation at the breaking stress and is the breaking strain. Expressed as a ratio of the increase in length over the original length, it has no dimensions.

Stiffness is measured by the slope of the elastic portion, O-x, of the stress-strain curve and equals $\frac{Px}{Ex}$. This is the elastic modulus expressed in grams per denier.

Average Stiffness is the ratio of the breaking stress P to the breaking strain E (as one-hundreth of the percentage elongation) and is expressed in grams per denier.

Elastic deformation (or recovery) is the deformation which is completely recoverable after removal of the load. It is a combination of immediate and delayed recovery. It is expressed as a percentage of the total elongation.

Permanent Set is that amount of elongation which is not recoverable even after an extended time. It is expressed as a perdentage of th total elongation.

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Toughness is measured by the area O-Y-U-E-O and expresses the total work required to rupture the material in grams per denier. The toughness index is the area O-U-E-O- and is an approximation of the actual toughness. It generally is lower than the actual toughness because portions of the curve will be above the line O-U especially for higher elongation materials. It is determined simply as one half the product of the breaking stress P and the breaking strain E in terms of unit elongation (one-hundredth of the percentage elongation).

The literature contains a number of tabulations of some of these properties for natural and synthetic fibers. A few of these are given here. Where the type of material, such as nylon type 300, is not specified in the original literature, it is not given in the table. Some of this work was done on the early form of these fibers which had no type designation and which may be different than the fibers which are now available. Saponified acetate is mentioned in a number of places without indicating the source. Fortisan is a saponified acetate and this trade name is used wherever it occurs in the literature.

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TABLE I Air-dry Strength of Some Fiber Materials*

Material	Density	Tenacity g/gx	Tensile Stress psi
Nylon	1.14	4.0 - 6.3	55,000 - 102,000
Silk (boiled off)	1.35	2.2 - 4.6	42,000 - 82,000
Wool	1.32	1.1 - 1.5	21,000 - 28,000
Acetate	1.32	1.2 - 1.5	22,000 - 28,000
Vinyl	1.35	1.8 - 3.6	35,000 - 69,000
Hemp	1.49	5.3 - 6.2	112,000 - 132,000
Jute	1.49	2.7 - 5.3	57,000 - 112,000
Flax	1.50	2.4 - 7.0	50,000 - 150,000
Viscose	1.52	1.4 - 4.5	39,000 - 97,000
Saponified Acetate	1.52	4.5 - 6.3	97,000 - 136,000
Cotton	1.52	2.0 - 5.0	44,000 - 109,000
Vinylidene	1.72	3.6 - 5.4	83,000 - 132,000
Glass	2.54	6 - 30	217,000 - 1,100,000
Steel (Structural)	7.8	0.4 - 1.1	50,000 - 125,000

*Ref. 9; Appendix II

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Additional properties of average stiffness and toughness are shown below:

TABLE II General Indices of Mechanical Character of Some Fiber Materials **

Tenacity g/gx		Wet. Stiffness g/gx		Toughness gx. cm / gx/cm	
				*Dacron 5500	0.65
Saponified Acetate	6.3	Glass	290	Vinylidene	0.56
*Nylon 300	6.3				
*Dacron 5100	6.0				
Glass	5.8	Flax	270	Nylon (reg.)	0.45
				*Nylon 300	0.44
Nylon (strong)	5.8	Hemp	200	Nylon (strong)	0.41
				*Dacron 5100	0.30
Flax	5.5	Abaca	175	Silk	0.30
Ramie	5.0	Ramie	167	Vinyl-1	0.30
Abaca	4.6	Sisal	127	Vinyl-2	0.25
Viscose 0	4.5	Saponified Acetate	105	Viscose HT	0.20
Nylon (reg.)	4.5	Viscose 0	75	Viscose MT	0.19
		*Dacron 5100	60		
Vinylidene	4.5	Cotton	57	Saponified Acetate	0.19
*Dacron 5500	4.3	*Nylon 300	45		
Hemp	4.0	Nylon (strong)	41	Viscose HT	0.17
Cotton	4.0	Silk	24	Acetate HT	0.16
Silk	3.8	Viscose HT	23	Cotton	0.14
Sisal	3.7	Nylon (reg.)	22	Viscose 0	0.14
Vinyl-2	3.3	Vinyl-2	22	Cupram. HT	0.13
Viscose MT	3.0	Vinylidene	18	Ramie	0.08
Viscose MT	2.4	Viscose MT	15	Abaca	0.07
		*Dacron 5500	14.3		
Vinyl-1	2.0	Cupram. HT	14	Glass	0.06
Cupram. HT	1.9	Viscose HT	10	Flax	0.06
Viscose, HT	1.8	Vinyl-1	7	Sisal	0.05
Acetate	1.3	Acetate HT	5	Hemp	0.04

* Calculated values added to original table

Data on some of the newer fibers as obtained from the curves of Figure 3 have been inserted for comparison.

** Reference 9, Appendix II

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More recent information is contained in a chart on fiber properties published by the Textile World (9). Some of this data is reproduced in Table III.

Table IV gives data calculated from the curves on yarns of Figure 2 as determined by Susick and Backer (11).*

The agreement between the calculations from various sources is fairly good considering that the rates of loading were different. The cotton figures from Susick and Backer data on staple yarns are understandably lower than the figures on cotton fibers.

These tables show that high tenacity fibers such as glass, saponified acetate, flax, and ramie, which have also a high average stiffness, have relatively poor toughness and therefore indicate brittleness. Nylon, Dacron, and Orlon which also are in the upper tenacity range, have less average stiffness, but much greater toughness index.

The materials then which have the desirable properties of tenacity, average stiffness, and toughness better than those of cotton are Nylon, Dacron, Orlon, Vinylidene Chloride and perhaps Saponified Acetate. Polyvinylidene chloride (Saran) is rather low in tenacity; Saponified Acetate is high in average stiffness.

*Appendix II

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TABLE III PROPERTIES OF TEXTILE FIBERS

Fiber	Tensile Strength g/d Std.	Wet.	Std. Loop	Elongation Per Cent	Tensile Stress lbs/in²	Ave. Stiff. gpd.	Ave. Toughness g/cm d/cm	Sp.G.
Viscose Reg.	1.5-2.4	0.7-1.2	1.0-1.5	15-30	29-45,000	11.1	0.19	1.5-1.52
" MT	2.4-3.0	1.2-1.7	1.5-1.8	12-20	46-58,000	15.6	0.21	"
" HT	3.0-4.6	1.9-3.0	1.6-2.1	9-17	58-88,000	25.5	0.22	"
Cupramm.	1.7-2.3	0.95-1.25	1.0-1.5	10-17	33-44,500	15.5	0.15	1.52-1.54
Acetate RT	1.3-1.5	0.8-1.2	0.9-1.3	23-30	22-28,000	5.5	0.17	1.32
" Saponified	7.0	6.0	—	6.0-6.5	136,000	116.6	0.21	1.5
" High El.	1.3-1.6	0.86-0.97	—	45-50	22,000	3.3	0.35	1.3
Nylon Reg.	4.7-5.6	4.2-5.0	4.0-4.8	25-28	68-81,000	20	0.56	1.14
Nylon HT (300)	6.4-7.5	5.7-6.6	5.2-6.2	17-19	86-109,000	39	—	1.14
Glass	6.3-6.9	5.4-5.8	1.0-1.4	3-4	204,000	322	0.07	2.54
Vinylidene Cl	1.4-2.3	1.4-2.3	0.7-1.5	15-30	15-45,000	20	0.62	1.68-1.75
Polyethylene	1.0-2.5	1.0-2.5	—	20-60	11-30,000	2-12	0.3	0.92
Orlon	4.4-5.2	3.6-4.8	3.3-3.7	15-17	65-74,000	28	0.44	1.17
Dacron (5500)	4.0-5.0	4.0-5.0	3.9-4.4	20-30	71-88,000	13-25	0.49-0.63	1.38
Vinyon H	2.8-3.5	2.8-3.5	—	25-35	51-59,000	10.5	0.45	1.32
Aralac	1.1-1.2	0.53-0.57	—	30-35	17.6-19,200	2.8-3.4	0.18-0.21	1.25
Cotton	3.6-3.7	—	—	3-7	44-109,000	57-60	0.15	1.54

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TABLE IV. MECHANICAL PROPERTIES OF YARNS

Yarn	Tenacity g. per grex	Elongation %	Ave. Stiff, g. per grex	Toughness Index g/cm. grex cm.
Fiberglass	5.81	2.3	253	0.07
Cotton 50/1	1.56	4.6	33	0.04
H.T. Fortisan	6.68	5.8	115	0.19
Cotton 12/1	1.37	7.9	17	0.05
Viscose	1.89	14.7	13	0.14
Saran	1.91	15.5	12	0.15
Vinyon NOZZ	3.60	15.7	23	0.28
H.T. Viscose	2.51	15.8	16	0.20
Orlon	4.19	16.6	25	0.35
Dacron	5.17	18.2	28	0.47
Silk	4.39	19.9	22	0.44
Acetate	1.23	20.5	6	0.13
Nylon	5.52	23.3	24	0.64
Vinyon NONU	2.85	31.1	9	0.54
Polyethylene	1.08	50.5	2	0.27

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The most comprehensive published study of stress-strain curves and tensile recovery behavior of textile yarns, all carried out under identical conditions, was made by Susick and Backer (11)*. The determinations were made on an Instron tester at an elongation rate of 5.0 inches per minute at 70°F. and 65% relative humidity. Most of these curves are shown in Figure 2. These curves again show that nylon, Dacron, Orlon and perhaps Fortisan, silk and vinyon NOZZ fall within the desirable range of properties.

Figure 3 shows additional plots of stress-strain curves of two types of Dacron and of Nylon type 300. Nylon type 300 has been treated to obtain about the minimum possible elongation. Dacron 5500 is hot stretched during manufacture to produce Dacron 5100.

In Figure 4 the curves for Fortisan, cotton, Dacron 5100, Nylon 300, Orlon and silk have been replotted on the basis of percentage of breaking strength as a different means of comparison of properties. It can be seen that Dacron 5100 and perhaps nylon 300 offer the best means of improving on the properties of cotton and Fortisan.

*Appendix II

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FIGURE 2

FIBER YARNS

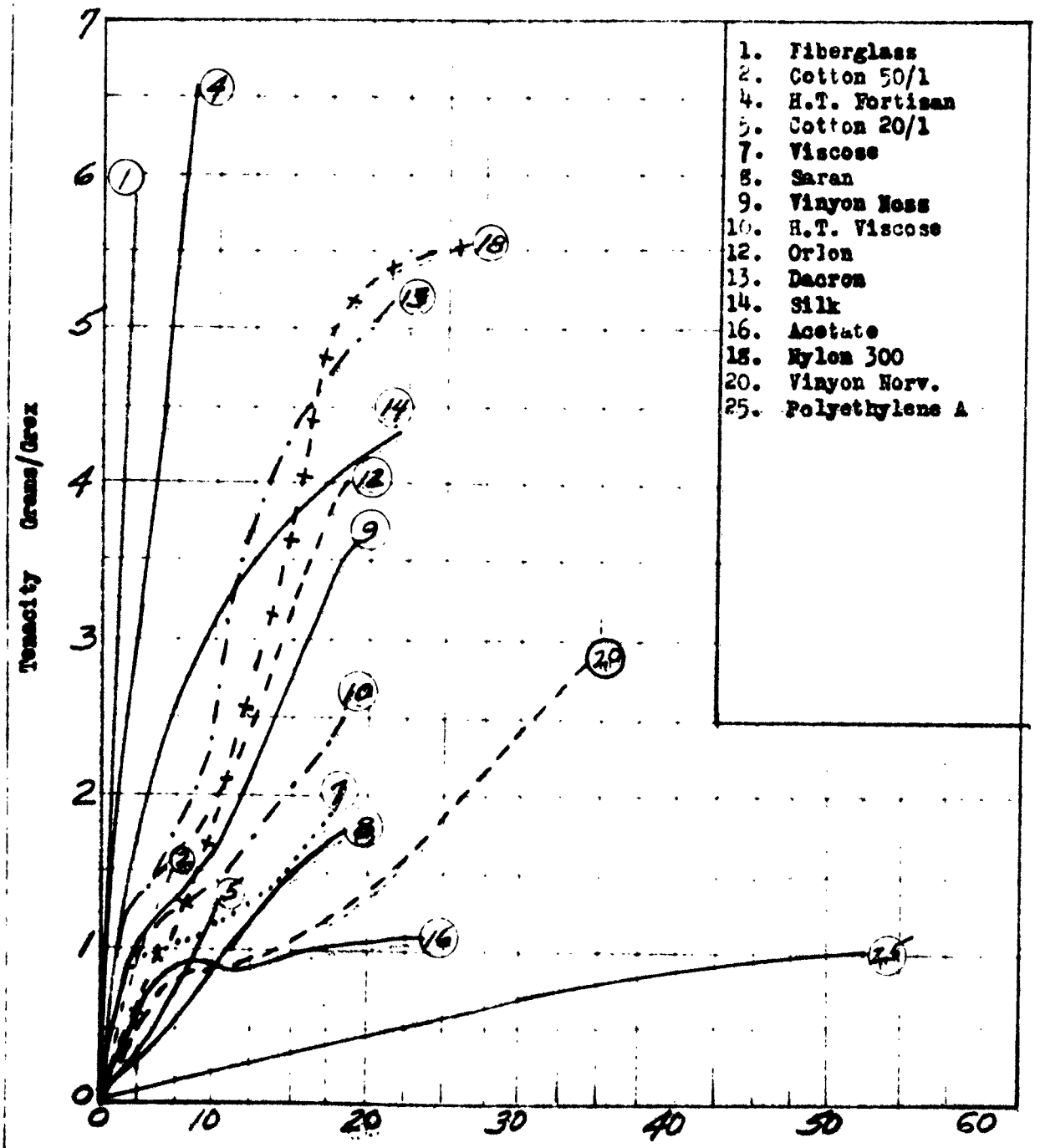

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FIGURE 3

FIBER YARNS

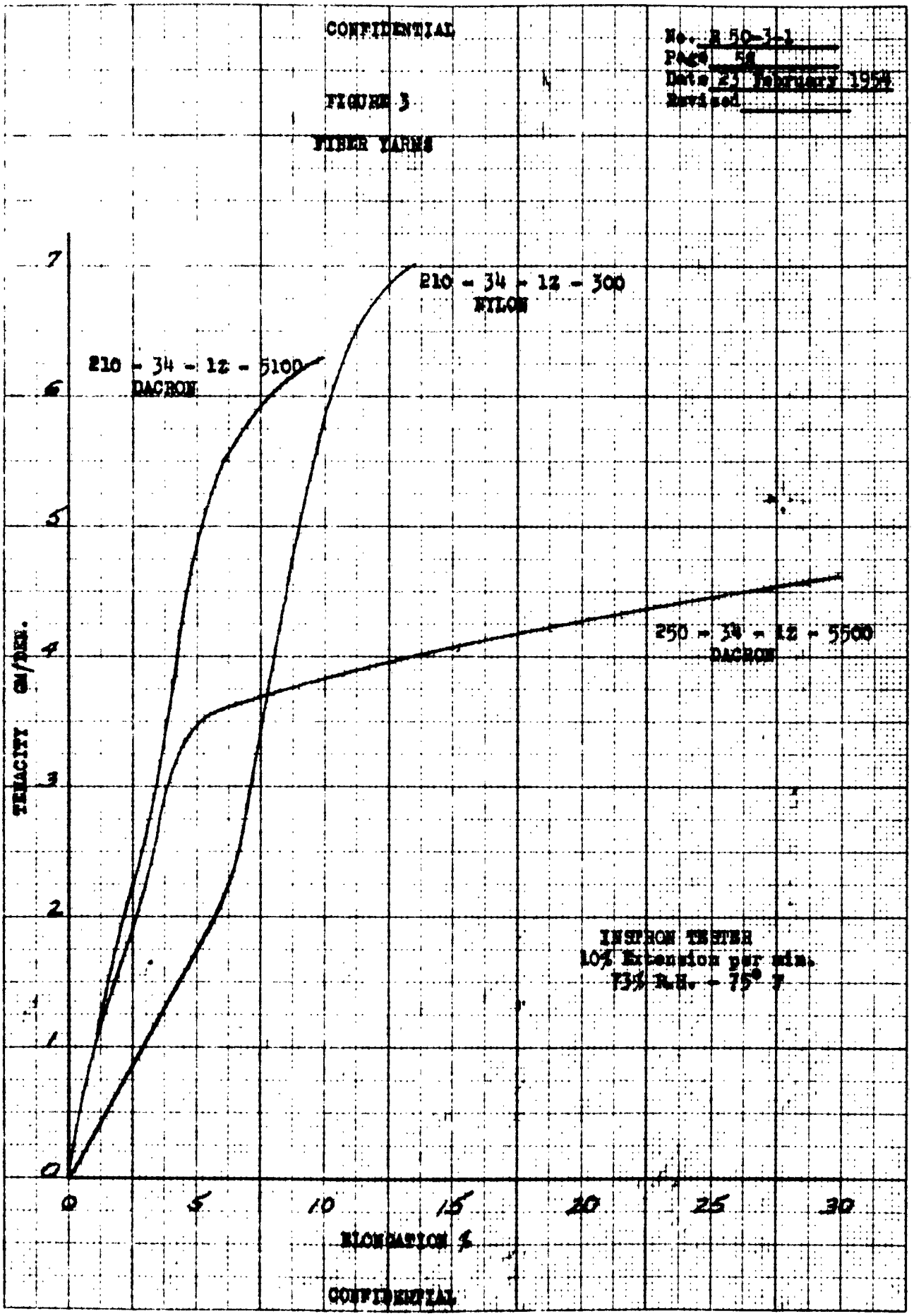

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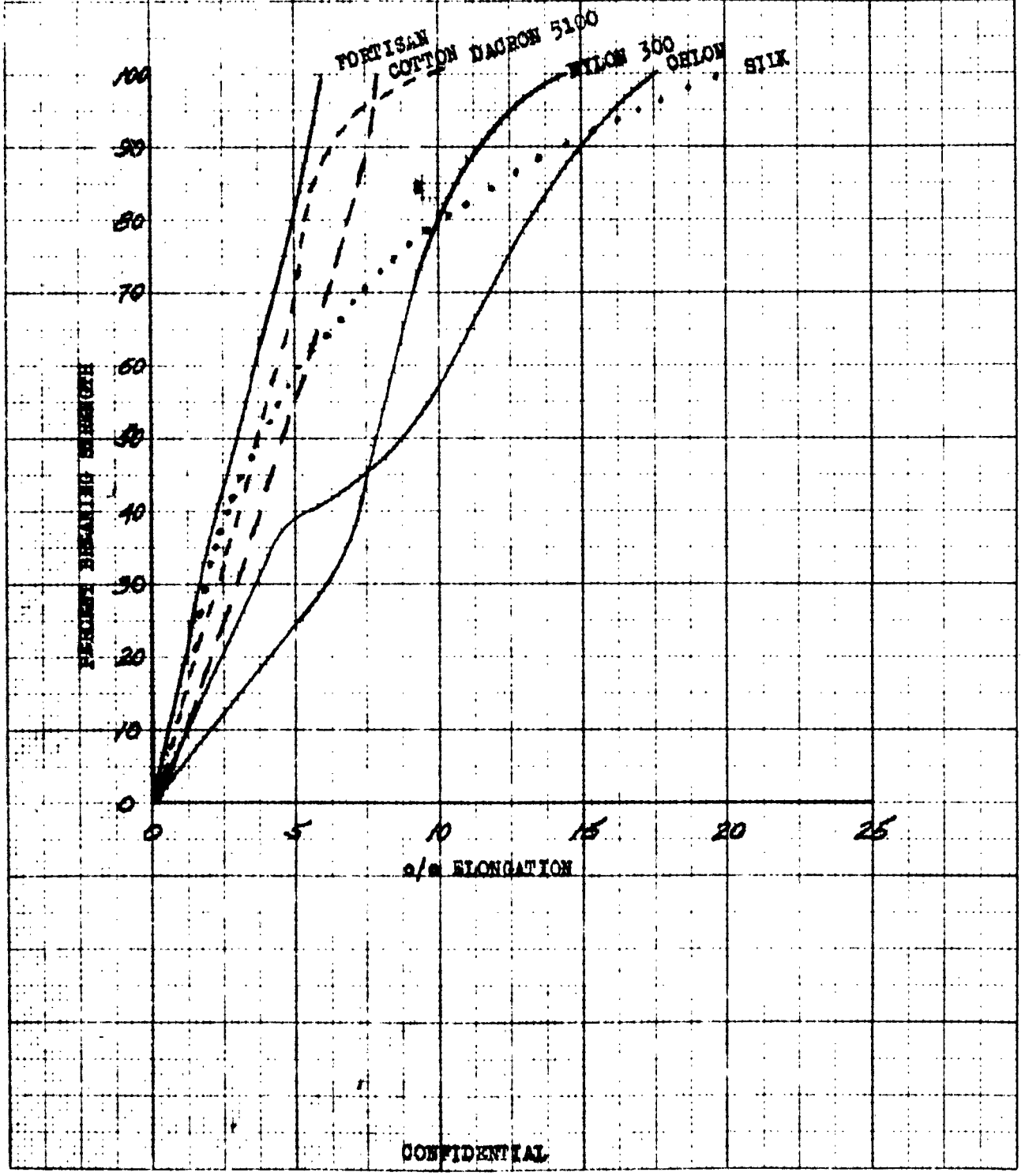
FIGURE 4

FIBER YARNS



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The shear strength of some textile materials was determined by Finlayson (12)*. Table V gives the results obtained at a rate of loading of 0.2 g./d./sec.

TABLE V Shear Strength of Fibers

Fiber	Shear Tenacity g/d		Tensile Tenacity g/d		Ext. at Break %	
	Dry	Wet	Dry	Wet	Dry	Wet
Fortisan H	1.17	1.06	8.00	6.70	7.9	7.9
Nylon	1.27	1.08	4.45	4.00	24.0	27.2
Linen	0.92	0.83	2.93	3.21	5.5	8.0
Vinyon	1.10	1.07	3.08	2.82	16.7	17.2
Viscose	0.72	0.35	1.96	0.79	14.4	15.5
Cuprama.	0.715	0.52	2.00	0.93	12.4	12.0
Silk	1.31	1.00	3.50	2.80	17.0	28.0
Cotton	0.96	0.87	2.63	2.49	6.4	4.1
Celanese	0.65	0.56	1.32	0.84	24.0	30
*Nylon	>1		5.0			
*Terylene	>1		6.25			
*Acrylonitrile types	0.8-1.0		3.5-4.2			

* Data from R.R. Roberts of the Chemstrand Corporation

*Appendix II

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The bending fracture of some fibers was studied by Thompson and Traill (13)*. Single filaments were bent to fracture through 180° under 1 g. tension. The results are given in Table VI.

TABLE VI. Bending Fracture of Fibers

Fiber	Breaking load, g.	Diameter in microns	Ave. No. of Bends
Wool	4	24	Some unbroken at 20,000
Nylon	6	14	Some unbroken at 20,000
Cotton	4.5	17	3,200
Silk	6	15	1,800
Acetate	4	19	150
Viscose	4	13	75
Glass	***	8	1

5.1.2 Effect of External Factors on Properties

A number of external factors affect the nature of the stress-strain curves. They are temperature, humidity, and time effects. For most materials, increases in temperature and humidity cause a loss of strength and increased elongation. An increase in rate of loading increases the strength and elastic modulus, but decreases the toughness index.

Meredith (17)* has stated that, "An increase in rate of loading of 10 times will produce an increase in strength of 10%, or expressed mathematically, $F/F_{10} = 1 + 0.1 \log_{10} (R/R_{10})$ where F = load at any given rate of loading R, and F_{10} = load at a standard rate of loading R_{10}. The value of R is the quotient of the known rate of loading in grams per minute and the average denier of the sample tested."

Figure 5 shows the effect of rate of loading on the tensile behavior of nylon (9)*.

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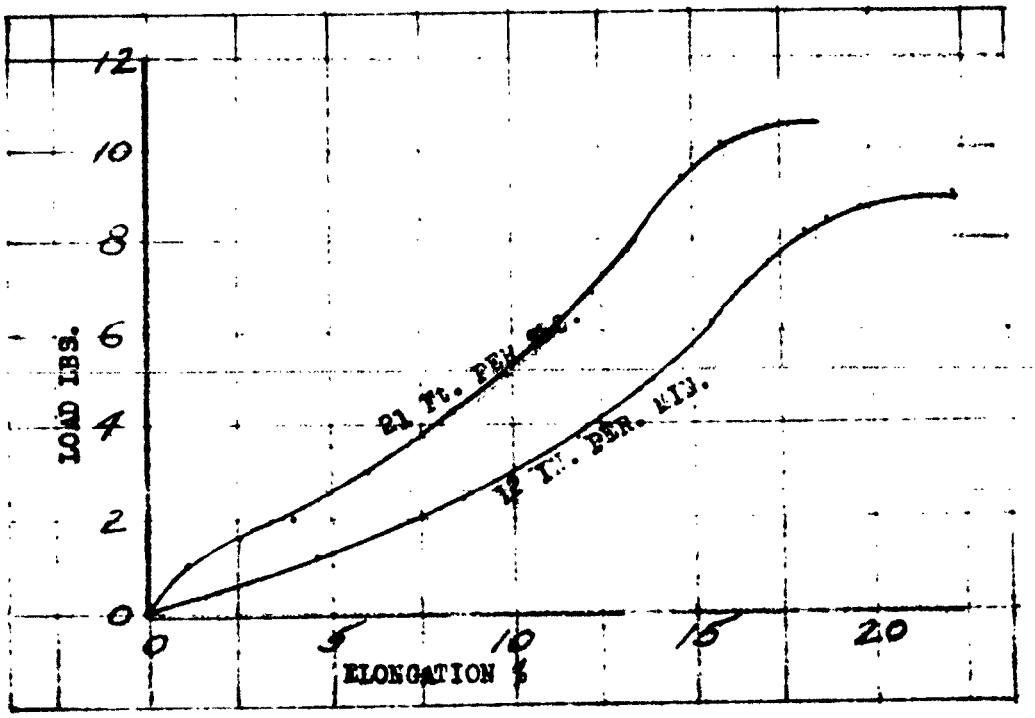
FIGURE 5



It has been shown, however, that the greater the curvature of the stress-strain curve, the greater will be the effect of rate of application of load. (7)* This effect is shown in Figures 6 and 7.

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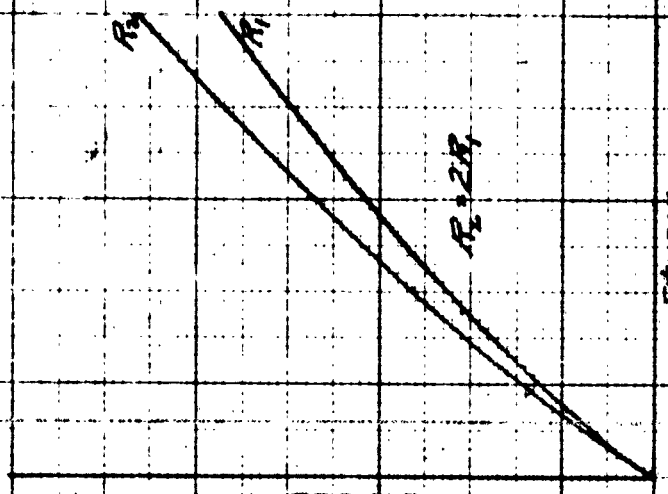

FIGURE 7

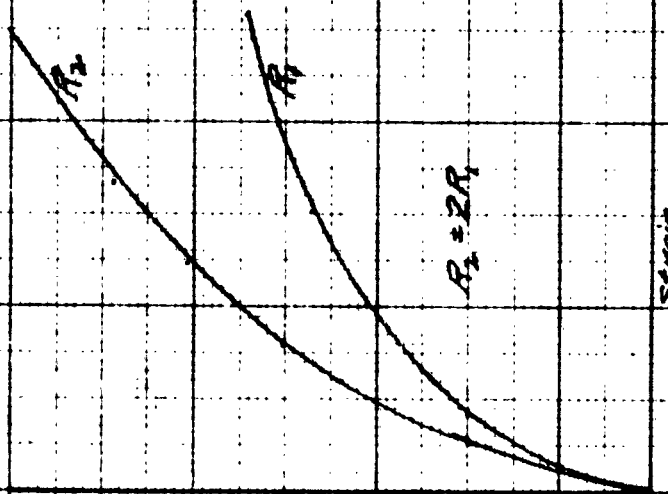

FIGURE 6

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This means that the tensile behavior of fibers such as glass, Fortisan, and perhaps cotton is affected less by changes in rate of loading than the tensile behavior of nylon, Dacron, Orlon, and silk.

Static load tests are of considerable interest, but very little information is available. Data on fibers obtained from DuPont was plotted to give the curves shown in Figure 8. Fortisan shows the greatest decrease in breaking strength, dropping from 6.5 g/d to 3.1 g/d at 160 hours compared to nylon which drops from 4.55 g/d to 3.4 g/d (This is not high tenacity nylon).

This may mean that after being subjected to a static load for a long period of time the tenacity will have dropped to about 45% of the original value of Fortisan, 67% of the original value of Nylon, and about 60% of the original values of orlon, viscose, and acetate. This property could be of great importance in an airship envelope kept under load for long periods, which is then subjected to an increased stress or impact. The force necessary to cause rupture would be a much lower percentage of the original breaking strength than when the envelope was first placed under load. In other words, the factor of safety may be considerably under that of the original design after the ship has been in service for some time.

Static load tests on Neoprene coated Fortisan fabrics carried out by Goodyear, showed a linear relation between load and log of time to break. Busse, Lessig, Loughborrough, and Larrick (14)* found a linear relationship between the log of breaking time and static load on cotton cords. Other fibers may or may not exhibit this behavior.

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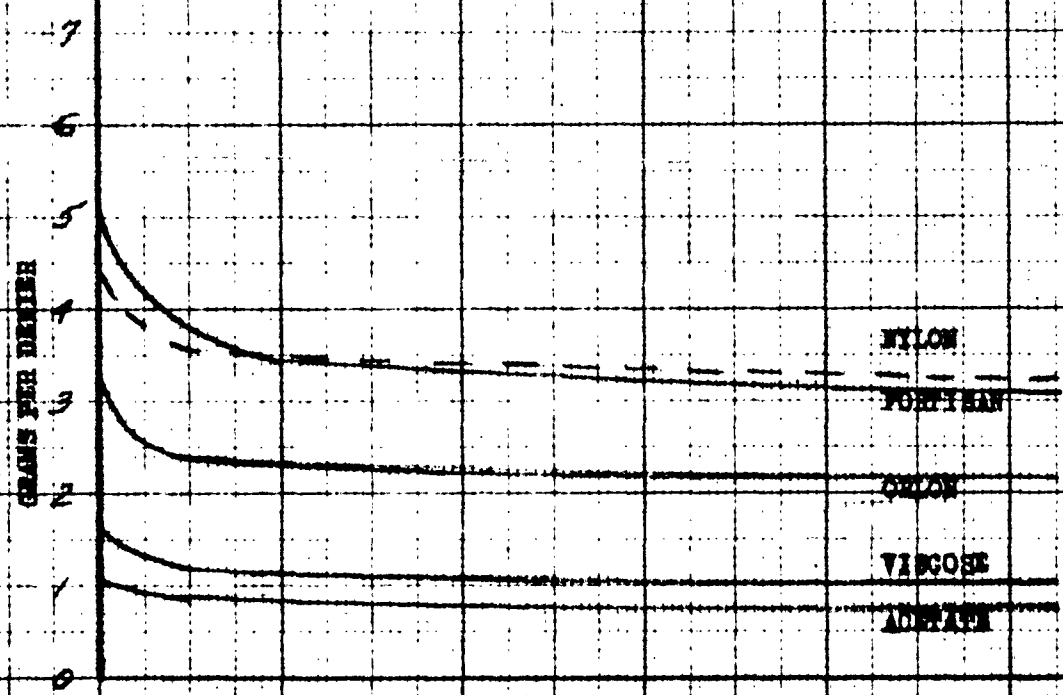
FIGURE 8



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Creep is a factor in static load tests, and of considerable importance for airship envelope applications. Leaderman (8)* made a thorough study of this phenomenon. Of particular interest are the plots of "scale factor" against stress shown in Figure 9.

The "scale factor" is a measure of resistance to creep. The curves show that nylon behaves differently than viscose, acetate, or silk in that after a certain load, further increases in load cause little change in creep, while the other materials creep more with increased load.

Dillon and Prettyman (15)*, in their work on tire cords, found that cotton, rayon, and Fortisan cords gave nearly linear creep curves (elongation vs. log time) in the range of 0.002-2 hrs., while nylon showed an increase in slope.

According to information from du Pont, Dacron creeps much less than nylon.

The effect of humidity on the stress-strain curves of some fibers is shown in Figure 10. (9)*.

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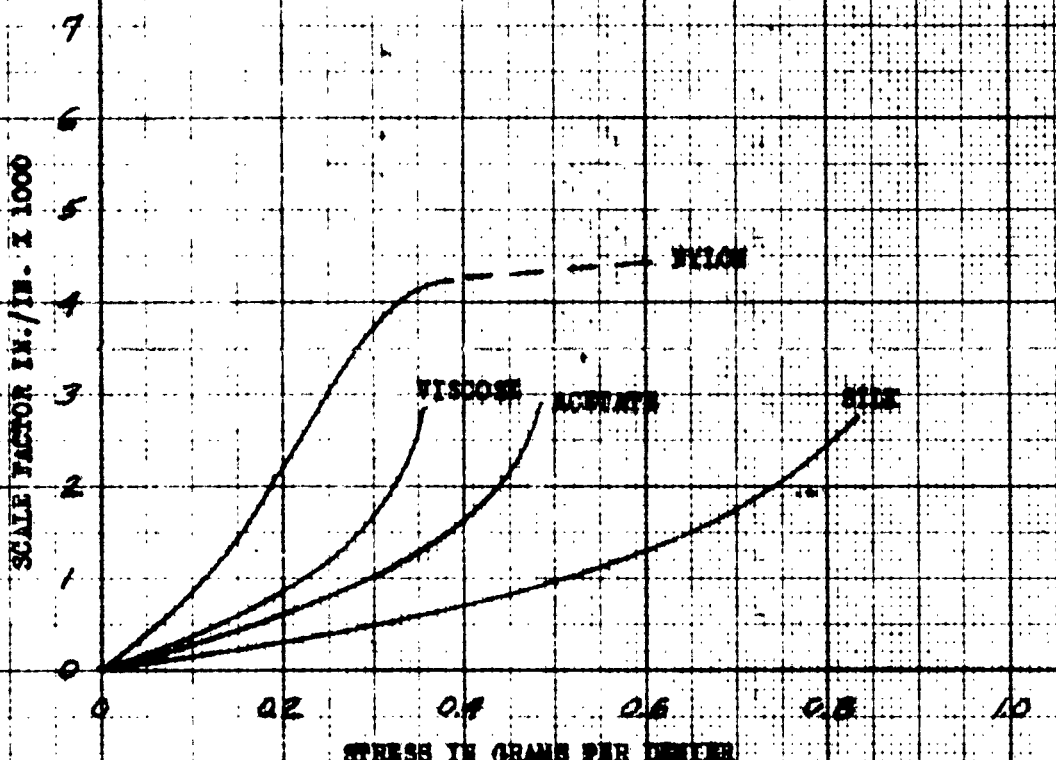
FIGURE 9



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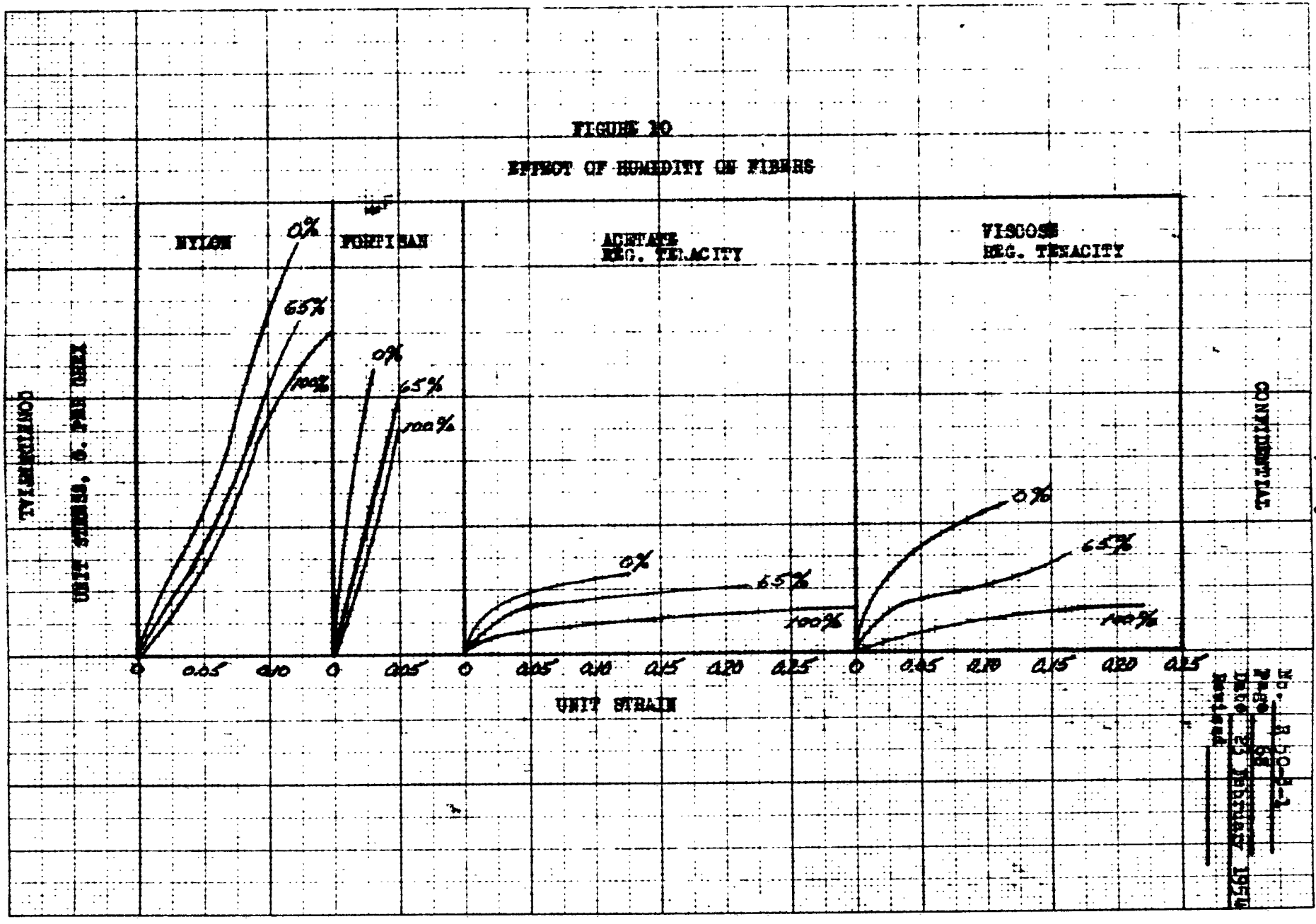

FIGURE 20

EFFECT OF HUMIDITY ON FIBERS

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The effect of temperature on the tenacity of nylon 300 is shown in Figure 11. (16)*. Curves shown to us by du Pont for Orlon and Dacron had the same slope.

Dillon and Prettyman (15)* in their work with tire cords found a decrease in tenacity for viscose rayon with increasing temperature; a decrease in tenacity of cotton over the range of 20-100°C. and then little change up to 165° C.; a decrease in tenacity of Fortisan in the range of 20-100° C. and then a slight increase; and a rapid decrease in the tenacity of nylon.

Changes in temperature cause changes in length of fibers. Nylon exhibits the behavior of shrinking with increase in temperature as shown in Figure 12. (16)*.

A tension of about 0.4 g/den. is required to prevent shrinkage. If shrinkage is not prevented then ultimate elongation is increased.

The curves on the original fiber and the fiber which had been restrained during heat treatment are almost identical, but the fiber which had been allowed to shrink without restraint has increased considerably in elongation.

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FIGURE 11

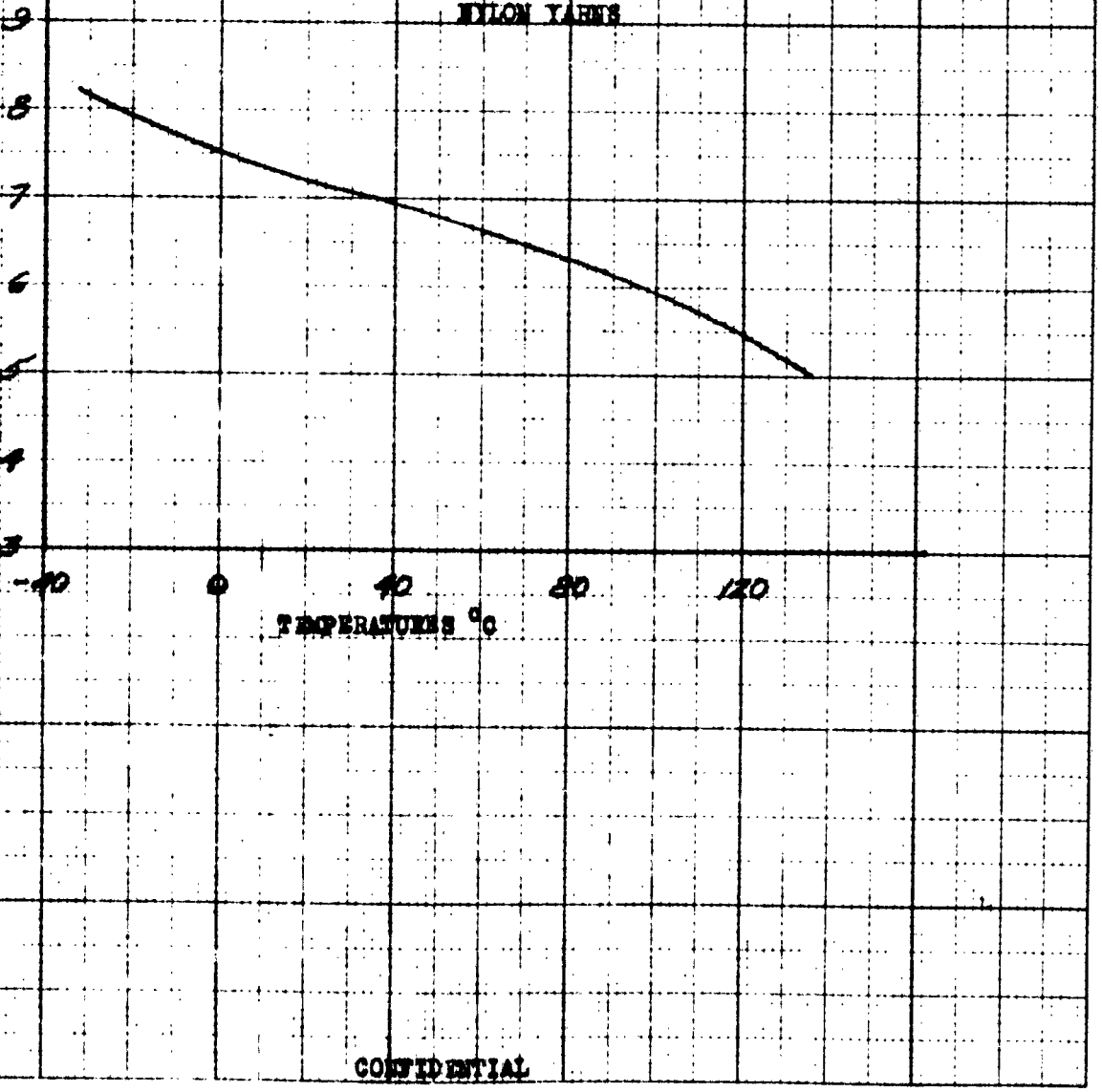

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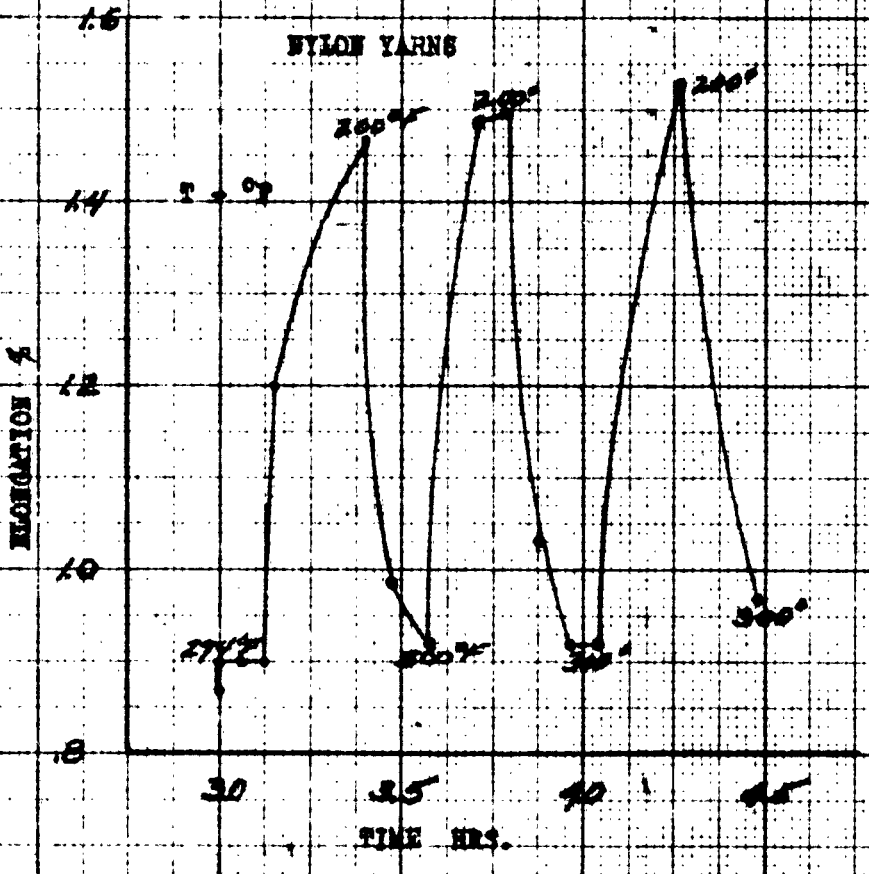
FIGURE 12



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It is common practice to "heat-set" nylon fabrics after they have been woven to decrease the dimensional changes which occur during further processing. Nylon is never absolutely set. Apparently subsequent heat treatment even at a temperature lower than the original setting temperature will cause some relaxation and increase in elongation. There is also some immediate and delayed recovery after hot stretching of nylon tire cords. According to results obtained at Walter Kidde Company, the shape of the stress-strain curve of Nylon 300 cannot be changed much by hot stretching. Minimum elongation obtainable is about 14%. There is also some feeling that the properties of the cord change during the process of making the tire, due mainly to elevated temperatures during calendaring and curing.

Figure 13 shows the effect of heat treatments on Dacron yarns. Elongation increases by 11% if shrinkage is allowed to take place. There is little change in elongation if the yarn is restrained.

All fibers exhibit a combination of delayed and immediate recovery as well as permanent set, the amount depending upon the extent of elongation and time under load.

A study of elastic recovery was made by Meredith (17)*. Some results are shown in Figures 14 and 15 below.

A more detailed study was made by Susick and Backer (11)* who isolated immediate elastic recovery, delayed recovery, and permanent set. Their results are shown in Figure 16.

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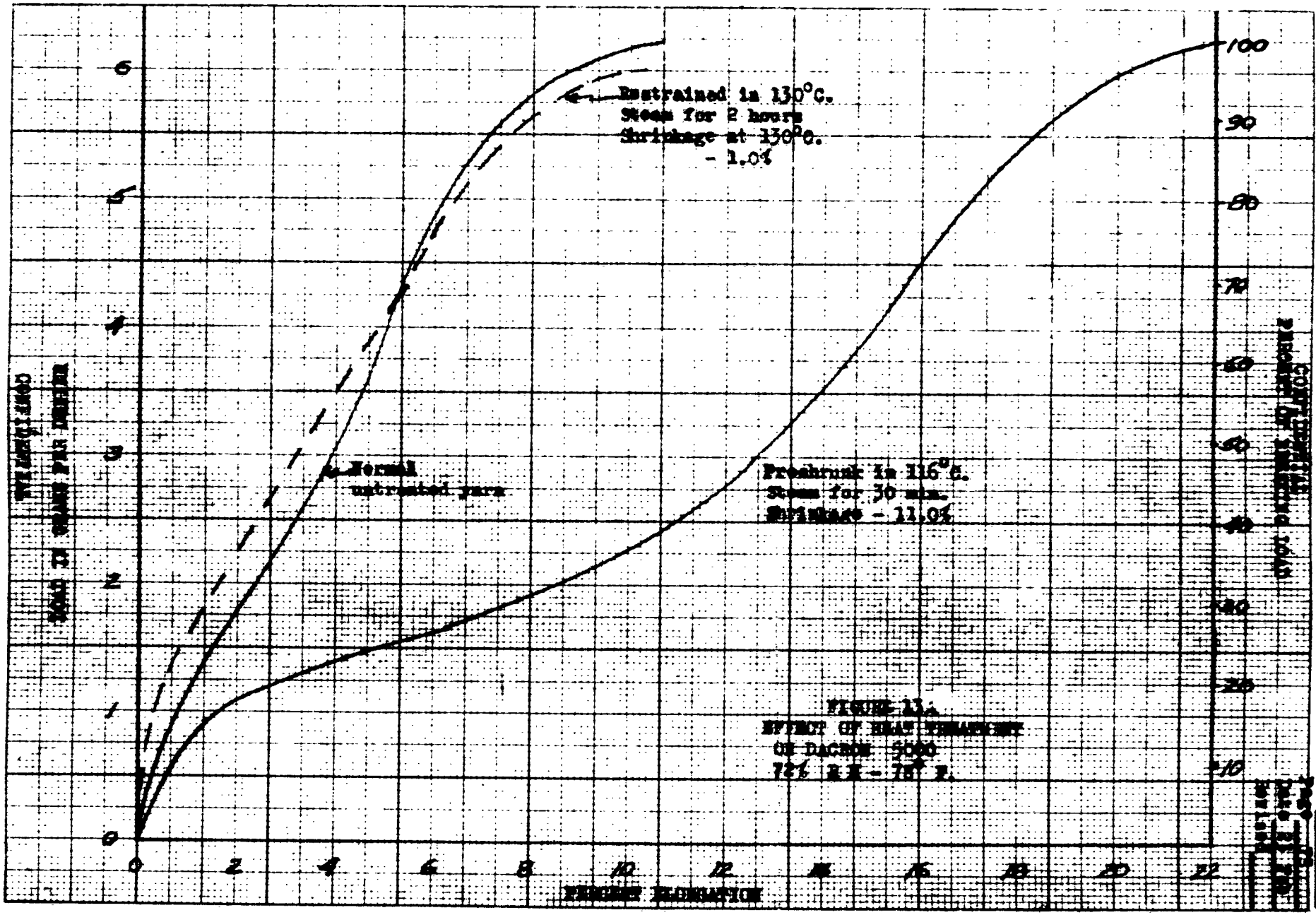

FIGURE 13.
EFFECT OF HEAT TREATMENT
ON DACRON 5000
72% R.H. - 78° F.

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Elkton, Maryland
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FIG. 14

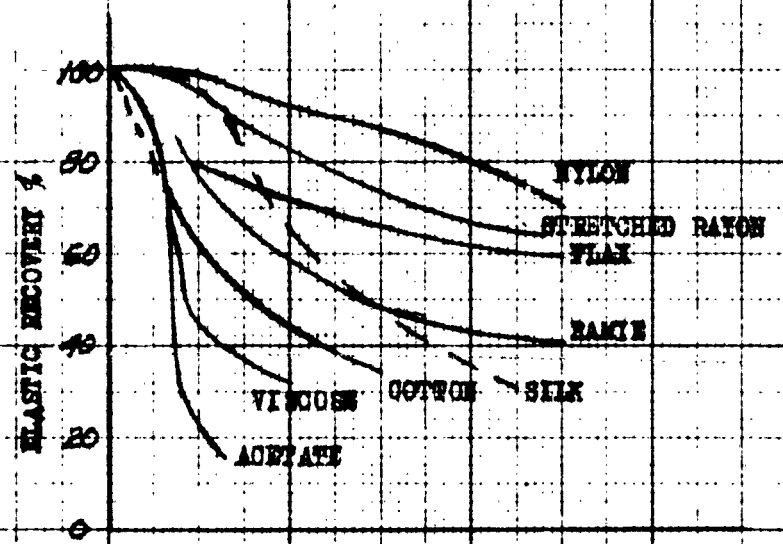
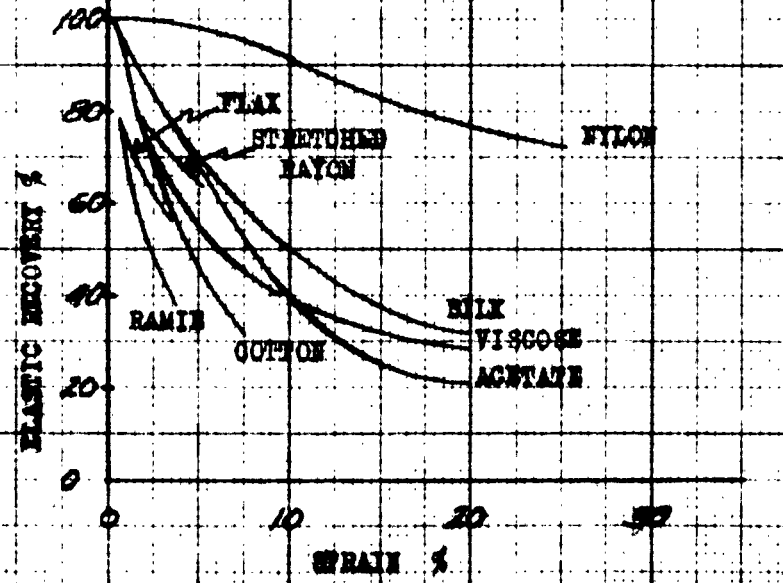


FIG. 15



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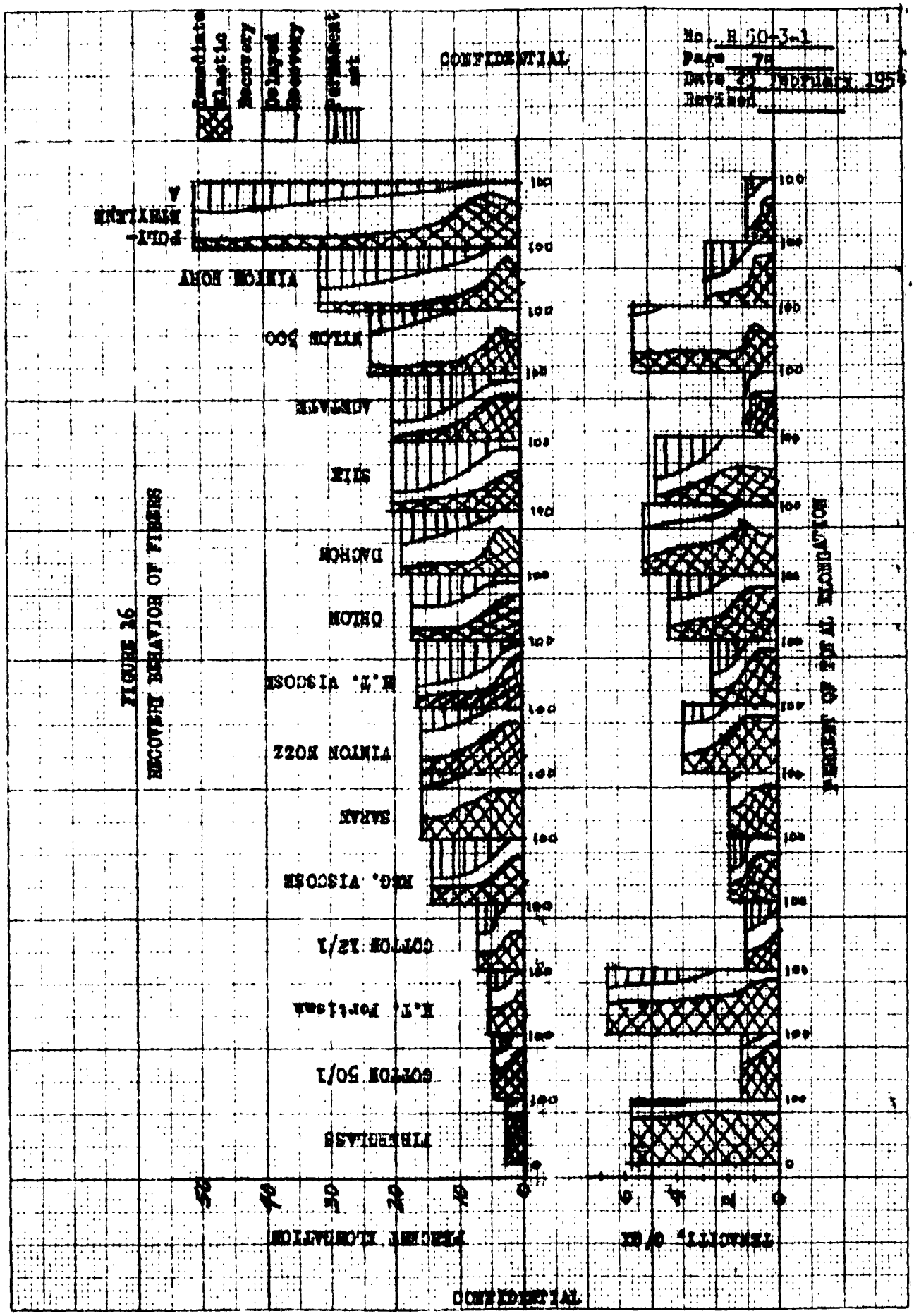

FIGURE 16
RECOVERY BEHAVIOR OF FIBERS

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Of the higher tenacity fibers, nylon 300 and Fiberglas show a low degree of permanent set. Dacron has considerably more. The type Dacron used is not specified but probably corresponds to Dacron 5500. The work was done in the experimental stage when Dacron was known as Fiber V. Nylon has a large area of delayed recovery; that is, a high percentage of total elastic recovery is delayed. Silk has a very high permanent set at high loads, none at low loads.

According to the work of Schiefer (18)* on flexural fatigue, fabrics made from acetate rayon, Fortisan, and silk show much more of a percent decrease in tensile strength as a result of folding than do fabrics made from viscose rayon, nylon and cotton. Of particular importance in resisting flexing fatigue is the ability of fibers in a yarn or yarns in a fabric to move freely. When movement is impaired, poor flex life is the result.

It has been pointed out by Hamburger (21)* that it is important to know the change which takes place in the load-elongation diagram of a material when subjected to loading and unloading cycles, if the condition occurs in actual use. If secondary creep occurs during the initial load, then the curve of the second loading cycle shows a lower elongation. This means that the tensional stiffness has increased and the toughness has decreased. If this change is considerable, failure may occur during a loading cycle, which would not cause failure of the material originally.

According to Susich and Backer (11)*, it is known that repeated stressing and sustained elongation produce a similar effect on the tensile properties. A fabric subjected to a static load (which produces elongation) will suffer fatigue and probably loss in strength.

*Appendix II

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The application of repeated stress and recovery cycles to a fiber can change its behavior depending upon the amounts of immediate and delayed recovery, and permanent set for the load applied. It has been shown by Howard (19)*, Midgley and Pierce (20)*, Busse and co-workers (16)*, and others that cyclic strain application causes loss in strength which is not recoverable.

*Appendix II

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5.2 Approach to the Solution of Problem

There appears to be a number of approaches to the solution of the problem of a high strength, light weight envelope fabric, some of which are listed below:

a. Decrease the amount of neoprene coating on cotton to maintain present properties at a lower weight.

b. Produce a warp yarn coated cotton fabric having a higher strength weight ratio.

c. Replace the neoprene coating with a coating of lower specific gravity such as butyl rubber.

d. Use a fabric having a higher strength weight ratio than cotton and coat with neoprene at the lowest possible amount.

e. Use a woven fabric as in (d) or a warp yarn fabric of the same composition, but use a lower specific gravity coating.

f. Develop a coated fabric, each component of which performs a specific function. For example, use a high strength-weight ratio fabric combined with a continuous plastic film having a low hydrogen permeability, and a coated fabric with excellent resistance to outdoor exposure.

Since a number of these approaches are related, work was begun with fabrics of various synthetic fibers and with cotton and fortisan fabrics as controls. The various possibilities can be checked as work proceeds.

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5.3 Experimental Results

5.3.1 Uncoated Fabrics

5.3.1.1 Construction of Test Fabrics

Twenty different fabrics made from nylon, Orlon, Dacron, Fortisan and cotton were obtained for initial screening tests. These samples do not allow a strict comparison to be made of the various fiber materials because they vary in weight and construction. The choice of samples was limited to those immediately available from suppliers, and varied in size from two yards to one square foot. It was hoped that sufficient data could be obtained to eliminate some materials and weaves and then larger quantities of the most promising fabrics would be purchased. Most of these would have to be custom woven for this project.

The type of fabric and information on yarn construction is given in Table VII. It should be noted that nylon type 300 is no longer made as a 210 denier 69 filament yarn. Also, Dacron 5100 is no longer made by du Pont in 70 denier. Dacron type 5600 is semi-dull type 5500. Cotton fabric No. 5013 is standard RR basket weave.

The Dacron(type 5500)twill and Dacron (type 5100) basket weave fabrics were received at a later date. Their construction, and that of Dacron (type 5500) basket weave fabric, is given in Table VIII. Measured

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physical properties are listed in Table IX. Dacron 15023 (type 5100) is not as heavy as Dacron 15018 (type 5500) for equivalent tensile strengths. Elongation at 20% load is less. Tear strength is lower, possibly because there are fewer yarns per inch.

Tensile strength and elongation increase after scouring and still more after heat setting. This is due to shrinkage. Nylon fabrics behave the same way, but do not shrink as much.

Strength-weight ratios, as shown in Table X also change, and are lowest for the heat-set fabrics. The ratio is highest for the type 5100 fabric. Even this is not as high as the strength-weight ratios of the nylon fabrics.

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TABLE VII TEST FABRICS AND THEIR CONSTRUCTION

Fabric No.	Weave	Type	Denier	Filament	Turns per Inch	Twist	Finish	Thread Count Warp	Thread Count Fill	Wt Oz Per Yd. Sq
NYLON										
2417	2 x 2 Basket	300	210	69	3	S	Regular	76	59	4.15
2583/s	Rip-stop	300	210	34	7	Z	Heat Set	50	52	3.1
2673/9	Satin	300	W 70	34	10	Z	Heat Set	172	86	2.94
			F.100	34	¾	Z				
2680	Twill	300	W 70	34	10	Z	Regular	174	154	3.25
			F 70	34	3/4	Z				
2793	2 x 2 Basket	300	260	17	5	Z	Heat Shrunk	53	59	4.11
2887	Twill	300	W 70	34	10	Z	Heat Set	160	96	2.97
			F 100	34	1	Z				
2907	2 x 2 Basket	300	210	34	7	Z	Heat Set	69	70	4.33
2941	Taffeta	300	210	34	1	Z	Greige	40	40	2.2
2950	Mock Lena	300	W 210	34	7	S	Regular	74	68	3.83
			F 210	34	1	Z				
			80/2 Spun Nylon							
ORLON										
10,029	2 x 2 Basket	Bright	200	80	7	Z	Regular	84	79	4.57
10,030	3 x 3 Basket	Bright	200	80	7	Z	Regular	75	79	4.14
10,031	4 x 4 Basket	Bright	200	80	7	Z	Heat Shrunk	77	80	4.13
10,031/1	4 x 4 Basket	Bright	200	80	7	Z	Heat Shrunk	79	78	4.24
10,068	2 x 2 Basket	Bright	2 x 100	40	10	Z	Heat Set	51	56	2.86
DACRON										
15,000	2 x 3 Basket	5100	210	34	7	Z	Heat Shrunk	70	72	4.23
15,006	2 x 2 Basket	5600	2x70	34	10	Z	Heat Shrunk	85	89	3.53
FORTISAN										
7162	Twill	---	W 2x40	80	12	Z	Regular	138	88	2.98
			F 2x60	80	10	Z				
20,075	2 x 2 Basket	---	2x60	80	2.5	S	Greige			4.5
20,085	2 x 2 Basket	---	3 x 60	80	11	S	Greige			3.3
COTTON										
5013	5 x 5 Basket	Mercerised					Bleached	100	100	5.1

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TABLE VIII FABRIC CONSTRUCTION

Fabric	Weave	Denier	Yarn Count	Wt.Oz/Sq.Yd.	Finish
Dacron 15020 (5500)	2x2 Twill	75	65x65	2.60	Greige
			72x67	2.95	Scoured
			80x74	3.75	Scoured and Heat Set
Dacron 15023	2x2 Basket	220	62x64	3.85	Greige
			67x67	4.20	Scoured
			75x74	5.30	Scoured and Heat Set
Dacron 15018 (5500)	2x2 Basket	240	81x83	5.75	Greige
			88x88	6.50	Scoured
			96x98	8.05	Scoured and Heat Set

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TABLE IX MEASURED PHYSICAL PROPERTIES OF FABRICS

Fabric	Tensile Strength Lbs/In.	Elongation, % 20% Load	Elongation, % Ultimate	Tear Strength Lbs.
Dacron 15020-C	85.6x91.0	0.7x1.3	14.2x20.4	28.1x32.2
15020-S	101.2x92.8	0.8x1.2	24.9x28.4	35.4x35.3
15020-H	121.6x107.6	1.0x2.7	36.6x49.0	43.5x44.7
Dacron 15023-C	187.0x189.8	2.3x2.7	13.1x15.0	65.1x66.9
15023-S	206.6x204.2	2.3x3.3	21.1x24.8	74.5x73.3
15023-H	217.8x215.8	3.3x5.0	35.9x43.5	88.5x94.1
Dacron 15018-C	182.2x192.6	5.4x1.5	25.3x23.1	74.0x68.2
15018-S	208.4x220.2	4.8x2.5	34.8x32.1	91.4x76.4
15018-H	226.4x236.4	6.4x4.5	58.6x48.0	128.0x118.4

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TABLE X. CALCULATED PHYSICAL PROPERTIES OF FABRICS

Fabric	Strength Weight Ratio	Average Stiffness	Toughness Index
Dacron 15020-G	527x560	602x453	6.1x9.3
15020-S	549x503	407x326	12.6x13.2
15020-H	519x459	333x220	22.2x26.3
Dacron 15023-G	778x790	1430x1265	12.2x14.2
15023-S	787x779	980x824	21.8x25.3
15023-H	658x352	607x496	39.1x46.8
Dacron 15018-G	507x536	720x834	23.1x22.2
15018-S	513x542	600x686	36.3x35.4
15018-H	450x470	387x492	66.3x56.8

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5.3.1.2 Effect of after treatment

The physical properties of cotton, Fortisan, nylon type 300, and Dacron type 5500 fabrics were studied thoroughly. The cotton fabrics are those used in the present 3 ply cotton envelope. The Fortisan fabrics are the ones which were used in the Fortisan envelopes. The nylon and Dacron fabrics were woven for this project and designed to have the strength properties of the Fortisan fabrics. Each one was supplied in the greige, scoured and heat-set.

Scouring consisted of heating in a detergent solution for one hour at boiling temperature. The fabric then was ironed.

Another portion of the scoured fabric was heat-set at 425° F. for ten seconds on a Morrison machine. This is a dry heat treatment with the fill yarns unrestrained and with some tension on the warp yarns.

Such heat treatment allows the fabric to shrink. In addition, the fabric shrinks considerably during scouring. As a result, after treatment elongation is at a maximum instead of the minimum which seems desirable. Therefore, a portion of the greige fabric nylon 3142 was heat-set in a clip frame, using a fairly high warp tension. The clips keep the fill yarns from shrinking. Maximum temperature was 425° F. for 20-30 seconds. This sample is designated as 3142-HB.

Table XI lists the construction of the fabrics and their weight per square yard. The weight increases after scouring of nylon and Dacron, and increases again during heat setting. Heat-set nylon 3142 HB, however, is only slightly heavier than the greige fabric.

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Shrinkage which takes place in the finishing operations is reflected in physical properties as shown in Table XII. All of these results are the averages of five samples. Scouring causes an increase in tensile strength because the number of yarns per inch increases. Heat setting results in little change in tensile for nylon 3141 and nylon 3142, but causes a decrease for nylon 3143. Heat degradation probably overcomes the effect of shrinkage and may be greater for the finer yarns in the 3143 fabric. Dacron 1501S increases in strength after heat setting because of additional shrinkage.

Shrinkage results in increased elongation at the breaking point. For the nylon fabrics, this increase is greatest in the fill direction. That is, shrinkage is not uniform. The special heat set fabric, nylon 3142-HB, has an elongation only slightly higher than that of the greige fabric.

Table XII also includes elongations at 20% of the breaking load. These follow the same pattern as ultimate elongations. HR cotton and the Fortisan fabrics have very low elongations at 20% load. HB cotton falls in the same range as the nylon and Dacron fabrics. The special heat set nylon 3142 HB has elongations under 20% load, the same as those of the greige fabric.

Table XII shows also that nylon and Dacron fabrics have higher tear strengths than cotton and Fortisan fabrics. For nylon and Dacron fabrics, tear strength increases with increasing elongation due to finishing.

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Tear strengths of RR cotton, nylon 3141, nylon 3142 and Dacron 15018 are higher than 20 % of the breaking load. Tear strengths of Fortisan 373 and nylon 3143 are about equal to 20 % of the breaking load. The other fabrics have lower tear strengths. If each fabric was punctured while under 20 % load, only the first group would not fail by tearing. This reasoning may not be applicable to plied coated fabrics. Their tear strengths will be determined and compared with tensile strengths as above.

Calculated physical properties are listed in Table XIII. Mock leno weave nylon 3141 has the highest strength-weight ratio in the greige and scoured form. The other nylons and Fortisan are about the same, Dacron type 5500 has a much lower ratio, and the cotton fabrics have the lowest strength-weight ratios. Scouring nylon and Dacron fabrics increases the ratio in the warp direction, while heat-setting decreases it. Strength-weight ratios in the fill direction are decreased for nylon and increased for Dacron after scouring.

Average stiffness values show RR cotton and Fortisan to be the stiffer fabrics. Surprisingly, BB and HH cotton have low values. Stiffness of nylon and Dacron fabrics decreases after scouring and after heat-setting.

Toughness index values are much higher for nylon and Dacron fabrics than for cotton and Fortisan fabrics. This is due to the large differences in elongation. Changes due to finishing follow changes which occur in elongation.

physical properties are listed in Table IX. Dacron 15023 (type 5100) is not as heavy as Dacron 15018 (type 5500) for equivalent tensile strengths. Elongation at 20% load is less. Tear strength is lower, possibly because there are fewer yarns per inch.

Tensile strength and elongation increase after scouring and still more after heat setting. This is due to shrinkage. Nylon fabrics behave the same way, but do not shrink as much.

Strength-weight ratios, as shown in Table X also change, and are lowest for the heat-set fabrics. The ratio is highest for the type 5100 fabric. Even this is not as high as the strength-weight ratios of the nylon fabrics.

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2583/s	Rip-stop	300	210	34	7	Z	Heat Set	50	52	3.1
2673/9	Satin	300	W 70	34	10	Z	Heat Set	172	86	2.94
			F.100	34	½	Z				
2680	Twill	300	W 70	34	10	Z	Regular	174	154	3.25
			F 70	34	3/4	Z				
2793	2 x 2 Basket	300	260	17	5	Z	Heat Shrunk	53	59	4.11
2887	Twill	300	W 70	34	10	Z	Heat Set	160	96	2.97
			F 100	34	½	Z				
2907	2 x 2 Basket	300	210	34	7	Z	Heat Set	69	70	4.33
2941	Taffeta	300	210	34	1	Z	Greige	40	40	2.2
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			F 210	34	1	Z				
			80/2 Spun Nylon							
ORLON										
10,029	2 x 2 Basket	Bright	200	80	7	Z	Regular	84	79	4.57
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10,031/1	4 x 4 Basket	Bright	200	80	7	Z	Heat Shrunk	79	78	4.24
10,068	2 x 2 Basket	Bright	2 x 100	40	10	Z	Heat Set	51	56	2.86
DACRON										
15,000	2 x 3 Basket	5100	210	34	7	Z	Heat Shrunk	70	72	4.23
15,008	2 x 2 Basket	5600	2x70	34	10	Z	Heat Shrunk	85	89	3.53
FORTISAN										
7162	Twill	---	W 2x40	80	12	Z	Regular	138	88	2.92
			F 2x60	80	10	Z				
20,075	2 x 2 Basket	---	2x60	80	2.5	S	Greige			4.5
20,085	2 x 2 Basket	---	3 x 60	80	11	S	Greige			3.3
COTTON										
5013	5 x 5 Basket	Mercerized					Bleached	100	100	5.1

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Fabric	Weave	Denier	Yarn Count	Wt.Oz/Sq.Yd.	Finish
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			72x67	2.95	Scoured
			80x74	3.75	Scoured and Heat Set
Dacron 15023	2x2 Basket	220	62x64	3.85	Greige
			67x67	4.20	Scoured
			75x74	5.30	Scoured and Heat Set
Dacron 15018 (5500)	2x2 Basket	240	81x83	5.75	Greige
			88x88	6.50	Scoured
			96x96	8.05	Scoured and Heat Set

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15020-S	101.2x92.8	0.8x1.2	24.9x28.4	35.4x35.3
15020-H	121.6x107.6	1.0x2.7	36.6x49.0	43.5x44.7
Dacron 15023-G	187.0x189.8	2.3x2.7	13.1x15.0	65.1x66.9
15023-S	206.6x204.2	2.3x3.3	21.1x24.8	74.5x73.3
15023-H	217.8x215.8	3.3x5.0	35.9x43.5	88.9x94.1
Dacron 15018-G	182.2x192.6	5.4x1.5	25.3x23.1	74.0x68.2
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Fabric	Strength Weight Ratio	Average Stiffness	Toughness Index
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15023-H	658x552	607x496	39.1x46.8
Dacron 15018-G	507x536	720x834	23.1x22.2
15018-S	513x542	600x686	36.3x35.4
15018-H	450x470	387x492	66.3x56.8

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5.3.1.2 Effect of after treatment

The physical properties of cotton, Fortisan, nylon type 300, and Dacron type 5500 fabrics were studied thoroughly. The cotton fabrics are those used in the present 3 ply cotton envelope. The Fortisan fabrics are the ones which were used in the Fortisan envelopes. The nylon and Dacron fabrics were woven for this project and designed to have the strength properties of the Fortisan fabrics. Each one was supplied in the greige, scoured and heat-set.

Scouring consisted of heating in a detergent solution for one hour at boiling temperature. The fabric then was ironed.

Another portion of the scoured fabric was heat-set at 425° F. for ten seconds on a Morrison machine. This is a dry heat treatment with the fill yarns unrestrained and with some tension on the warp yarns.

Such heat treatment allows the fabric to shrink. In addition, the fabric shrinks considerably during scouring. As a result, after treatment elongation is at a maximum instead of the minimum which seems desirable. Therefore, a portion of the greige fabric nylon 3142 was heat-set in a clip frame, using a fairly high warp tension. The clips keep the fill yarns from shrinking. Maximum temperature was 425° F. for 20-30 seconds. This sample is designated as 3142-HB.

Table XI lists the construction of the fabrics and their weight per square yard. The weight increases after scouring of nylon and Dacron, and increases again during heat setting. Heat-set nylon 3142 HB, however, is only slightly heavier than the greige fabric.

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Shrinkage which takes place in the finishing operations is reflected in physical properties as shown in Table XII. All of these results are the averages of five samples. Scouring causes an increase in tensile strength because the number of yarns per inch increases. Heat setting results in little change in tensile for nylon 3141 and nylon 3142, but causes a decrease for nylon 3143. Heat degradation probably overcomes the effect of shrinkage and may be greater for the finer yarns in the 3143 fabric. Dacron 15018 increases in strength after heat setting because of additional shrinkage.

Shrinkage results in increased elongation at the breaking point. For the nylon fabrics, this increase is greatest in the fill direction. That is, shrinkage is not uniform. The special heat set fabric, nylon 3142-HB, has an elongation only slightly higher than that of the greige fabric.

Table XII also includes elongations at 20% of the breaking load. These follow the same pattern as ultimate elongations. HR cotton and the Fortisan fabrics have very low elongations at 20% load. BB cotton falls in the same range as the nylon and Dacron fabrics. The special heat set nylon 3142 HB has elongations under 20% load, the same as those of the greige fabric.

Table XII shows also that nylon and Dacron fabrics have higher tear strengths than cotton and Fortisan fabrics. For nylon and Dacron fabrics, tear strength increases with increasing elongation due to finishing.

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Tear strengths of RR cotton, nylon 3141, nylon 3142 and Dacron 15018 are higher than 20% of the breaking load. Tear strengths of Fortisan 373 and nylon 3143 are about equal to 20% of the breaking load. The other fabrics have lower tear strengths. If each fabric was punctured while under 20% load, only the first group would not fail by tearing. This reasoning may not be applicable to plied coated fabrics. Their tear strengths will be determined and compared with tensile strengths as above.

Calculated physical properties are listed in Table XIII. Mock leno weave nylon 3141 has the highest strength-weight ratio in the greige and scoured form. The other nylons and Fortisan are about the same, Dacron type 5200 has a much lower ratio, and the cotton fabrics have the lowest strength-weight ratios. Scouring nylon and Dacron fabrics increases the ratio in the warp direction, while heat-setting decreases it. Strength-weight ratios in the fill direction are decreased for nylon and increased for Dacron after scouring.

Average stiffness values show RR cotton and Fortisan to be the stiffer fabrics. Surprisingly, BB and HH cotton have low values. Stiffness of nylon and Dacron fabrics decreases after scouring and after heat-setting.

Toughness index values are much higher for nylon and Dacron fabrics than for cotton and Fortisan fabrics. This is due to the large differences in elongation. Changes due to finishing follow changes which occur in elongation.

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The greige, nylon and Dacron fabrics which had been heat-set with shrinkage restrained in the warp and fill directions, also were heated. Their properties before and after heating are listed in Table XIV. All the properties change very little after heating.

The properties of the original greige nylon fabrics and the heat-set greige fabrics are almost identical. The greige Dacron fabrics could not be restrained completely from shrinking. The weight after treatment is higher. Tensile strength, elongation, and tear strength are higher. With the proper equipment, heat-setting without change in properties, except heat stability, should be possible.

These heat-set greige fabrics appear to be the most desirable for airship envelope fabrics. Permeability for a given weight of coating may be decreased. This will be investigated.

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TABLE XI. FABRIC SPECIFICATIONS

Fabric	Weave	Denier	Yarn Count	Wt. Oz/Sq. Yd.	Finish
RR Cotton	5x5 Basket	-	105x100	5.15	Mercerized Singed Bleached
BB Cotton	Plain	-	116x107	2.8	Singed and Desized
HH Cotton	Plain	-	123x123	1.95	Singed and Desized
Fortisan 368	2x1 Twill	90	93x96	2.2	Greige
Fortisan 373	2x2 Basket	2x90	78x76	3.6	Greige
Nylon 3141	Mock Leno	210	64x66 69x69 70x72	3.7 4.05 4.35	Greige Scoured Scoured and Heat Set
Nylon 3142	2x2 Basket	210	56x60 60x62 64x65	3.4 3.7 4.0	Greige Scoured Scoured and Heat Set
Nylon 3142 HB	2x2 Basket	210	58x61	3.55	Heat Set
Nylon 3143	2x2 Twill	70	90x92 96x94 101x97	2.45 2.6 2.85	Greige Scoured Scoured and Heat Set
Dacron 15018	2x2 Basket	240	81x83 83x88 96x98	5.75 6.50 8.05	Greige Scoured Scoured and Heat Set
Dacron 15000	2x3 Basket	210	70x72	4.23	Heat Shrunk
Nylon 2941	Taffeta 300	210	40x40	2.2	Greige
Fortisan 20075	2x2 Basket	2x60	-	4.3	Greige

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TABLE XII. [illegible] PHYSICAL PROPERTIES OF FABRICS

Fabric	Tensile Strength Lbs/In.	Elongation, % 20% Load	Elongation, % Ultimate	Tear Strength, Lbs.
RR Cotton	137x130	1.5x2.0	6.2x5.2	53.2x56.4
BB Cotton	64.4x65.[illegible]	[illegible].4x6.0	1[illegible]x12.6	[illegible].0x4.5
HH Cotton	41.5x39.8	3.8x6.0	8.5x12.9	4.4x3.0
Fortisan 368	116.6x130	0.6x1.8	6.9x8.7	13.3x13.0
Fortisan 373	201.8x175.8	0.9x1.1	7.1x7.4	41.4x35.3
Nylon 3141-G	21[illegible]x222.6	[illegible].3x6.8	23.8x21.3	77.9x94.6
3141-S	233.4x234.0	7.7x9.6	29.7x35.3	88.3x91.8
3141-H	[illegible]	7.7x7.7	[illegible]x37.5	93.3x92.5
Nylon 3142-G	187x197	5.7x6.5	21.8x22.9	81.6x80.8
3142-S	195x192	6.2x9.5	28.2x34.3	91.9x84.4
3142-H	192.5x196	6.2x10.4	32.1x40.7	97.0x95.7
3142-HB	187x187	[illegible].5x6.4	24.4x26.1	
Nylon 3143-G	128.6x127.8	4.2x6.3	21.1x22.6	24.5x27.7
3143-S	143.6x127.2	6.1x7.5	26.8x36.0	31.1x31.9
3143-H	133.0x128.8	5.3x9.0	29.5x43.9	27.7x27.7
Dacron 15018-G	182.2x192.6	5.4x1.5	25.3x23.1	74.0x68.2
15018-S	208.4x220.2	4.8x2.5	34.8x32.1	91.4x76.4
15018-H	226.4x236.4	6.4x4.5	58.6x48.0	128.0x118.4

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TABLE VIII. CALCULATED TYPICAL PROPERTIES OF FABRICS

Fabric	Strength Weight Ratio	Average Stiffness	Toughness Index
RR Cotton	425x367	2210x2500	4.3x3.4
BB Cotton	368x375	511x521	4.1x4.1
HH Cotton	341x327	428x309	1.8x2.6
Fortisan 368	848x749	1690x1494	5.7x5.6
Fortisan 373	897x755	2840x2421	7.2x5.6
Nylon 3141-G	908x963	883x1044	25.0x23.7
3141-S	922x925	786x680	49.5x53.9
3141-H	866x862	610x626	45.4x44.0
Nylon 3142-G	840x835	858x860	30.4x34.0
3142-S	843x832	568x560	37.5x32.9
3142-H	780x784	600x482	30.9x39.9
3142-HB	843x843	766x716	28.8x24.4
Nylon 3143-G	838x834	610x565	13.6x14.5
3143-S	842x745	536x353	19.2x22.9
3143-H	748x724	451x293	19.7x28.3
Dacron 15018-G	507x536	720x834	23.1x22.2
15018-S	513x542	600x686	36.3x35.4
15018-H	450x470	387x492	66.3x56.8

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XIV. PROPERTIES OF SPECIAL TEAR STRENGTHS

Fabric	Tensile Strength Lbs/In.	Elongation, % 20% Load	Elongation, % Ultimate	Tear Strength Lbs.	Oz/Sq.Yd	Strength Weight Ratio
Nylon 3142G	187x187	5.5x6.3	24.4x26.1	81x82	3.55	842x842
Heated 30 Min 300° F.	181x201	4.6x5.7	21.8x24.1	77x80	3.55	815x905
Nylon 3143G	130x131	4.3x5.7	19.6x18.6	[illegible]x18.5	2.[illegible]	832x838
Heated 30 min. 300° F.	129x130	5.7x5.0	21.6x21.0	24.6x19.7	2.[illegible]5	811x815
Dacron 15020G	109x108	0.7x1.0	26.4x31.1	40.0x40.6	2.90	600x595
Heated 30 min. 300° F.	107x109	0.7x1.0	29.5x30.7	37.0x36.8	3.00	571x581
Dacron 15023G	200x205	3.3x2.7	28.5x23.6	77x84	4.45	720x738
Heated 30 min. 300° F.	205x209	3.3x3.0	26.3x27.8	72x78	4.55	720x735

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5.3.1.3 Elongation

Load-elongation curves were determined on a Scott tester for all the fabrics, both by the grab method and by the ravelled strip method. Data on breaking strength and elongation at rupture are summarised in Table XV for the fabrics and in Table XVI for yarns removed from these fabrics. For this preliminary work, all tests were run on warp yarn only.

Strengths by the grab method are higher than those determined by the ravelled strip method with the exception of basket weave cotton where the strengths are about the same. Elongations at break are the same within a few percent, with two exceptions.

When the two fabric curves and the yarn curve are plotted as percent of breaking strength versus elongation, the two fabrics curves are almost identical while the yarn curve has a lower elongation. This probably is due to the effect of weaving since the yarn curves have been corrected for the effect of crimp. All yarn tests were made on two sections of the same yarn and on at least one section of a different yarn.

Load-elongation curves by the grab method for all nylon samples are given in Figure 17. In general, the 70 denier, 34 filament yarn fabrics have about the same curves, and the 210 denier, 34 filament yarn fabrics form another group of curves with a somewhat higher modulus. Exceptions are fabric 2583/S whose curve falls well below those of all the other 210 denier fabrics and fabric 2941, the curve of which has a different shape.

Curves on the individual fabrics run by the grab method and by the ravelled strip method are given in Figures 18 to 26.

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Tests on yarns removed from the fabric are included also.

Curves for yarns which broke at less than one pound tensile, or 10% of the range of the tester, are not reliable.

A comparison of 210-34 yarn curves is given in Figure 27. The unwoven yarn obtained directly from a pirn has the highest modulus and lowest elongation, as well as the highest breaking strength. The yarn from a greige fabric is next in order of increasing elongation, a regular finished fabric yarn next, and a heat set fabric yarn last. On this basis, greige fabrics may give better results. The fabrics themselves fall in the same order.

Load-elongation curves for the two Dacron fabrics are given in Figure 28. The fabric made from Dacron 5600 is weaker than the Dacron 5100 fabric, as would be expected. However, the elongation is about the same, which is not the case with the original fibers where the elongation of Dacron 5600 is much higher. These are both heat-shrunk fabrics, indicating that this treatment may be responsible for different changes in elongation. Curves on the individual fabrics and yarns are shown in Figures 29 and 30.

Load-elongation curves for the Orlon fabrics are shown in Figure 31. Elongation is about the same except for fabric 10,068 which is the lightest in weight and is made up of lower deniers. The individual curves and yarn curves are shown in Figures 32 and 36.

The Fortisan fabric load-elongation curves are given in Figure 37. The twill fabric has a higher elongation than the basket weave fabrics. Separate curves are given in Figures 38 and 40.

The curve for RR cotton is given in Figure 41.

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TABLE XV. [illegible] OF TEST FABRICS - WARP DIRECTION

Fabric No.	Tensile Strength, Lbs. Raveled Strip	Lbs. Grab	Elongation % Raveled Strip	Grab
2417	205	274	28.0	29.3
2583/S	152	208	39.0	38.3
2673/9	174	242	33.0	38.0
2680	140	225	33.3	33.0
2793	161	243	33.3	33.6
2887	163	232	39.2	35.3
2907	218	300	40.8	38.3
2941	128	163	21.6	23.0
2951	233	300	26.3	35.0
10,029	165	212	20.3	22.0
10,030	168	199	21.0	21.0
10,031	139	175	21.6	20.0
10,031/1	155	170	21.0	23.0
10,068	95	106	19.0	17.3
15,000	184	257	27.0	26.6
15,008	129	186	18.0	26.0
7162	164	210	12.6	12.0
20,075	245	261	8.3	6.7
20,085	205	215	7.3	6.7
5013	136	132	4.6	7.0

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TABLE XVI. BREAKING STRENGTH AND ELONATION OF WARP YARNS REMOVED FROM FABRICS

Fabric No.	Tensile Strength, Lbs.	Elongation %
2417	2.6	20
2583/5	2.7	24
2673/9	0.5	17
2680	0.2	13
2793	2.9	28
2887	0.5	12
2907	2.9	27
2941	2.7	15
2950	2.7	18
10,029	1.8	16
10,030	1.9	17
10,031	1.9	17
10,031/1	1.5	17
10,068	1.3	15
15,000	2.2	19
15,008	1.1	16
7162	0.5	4
20,075	2.7	5
20,085	2.0	5
5013	0.9	2

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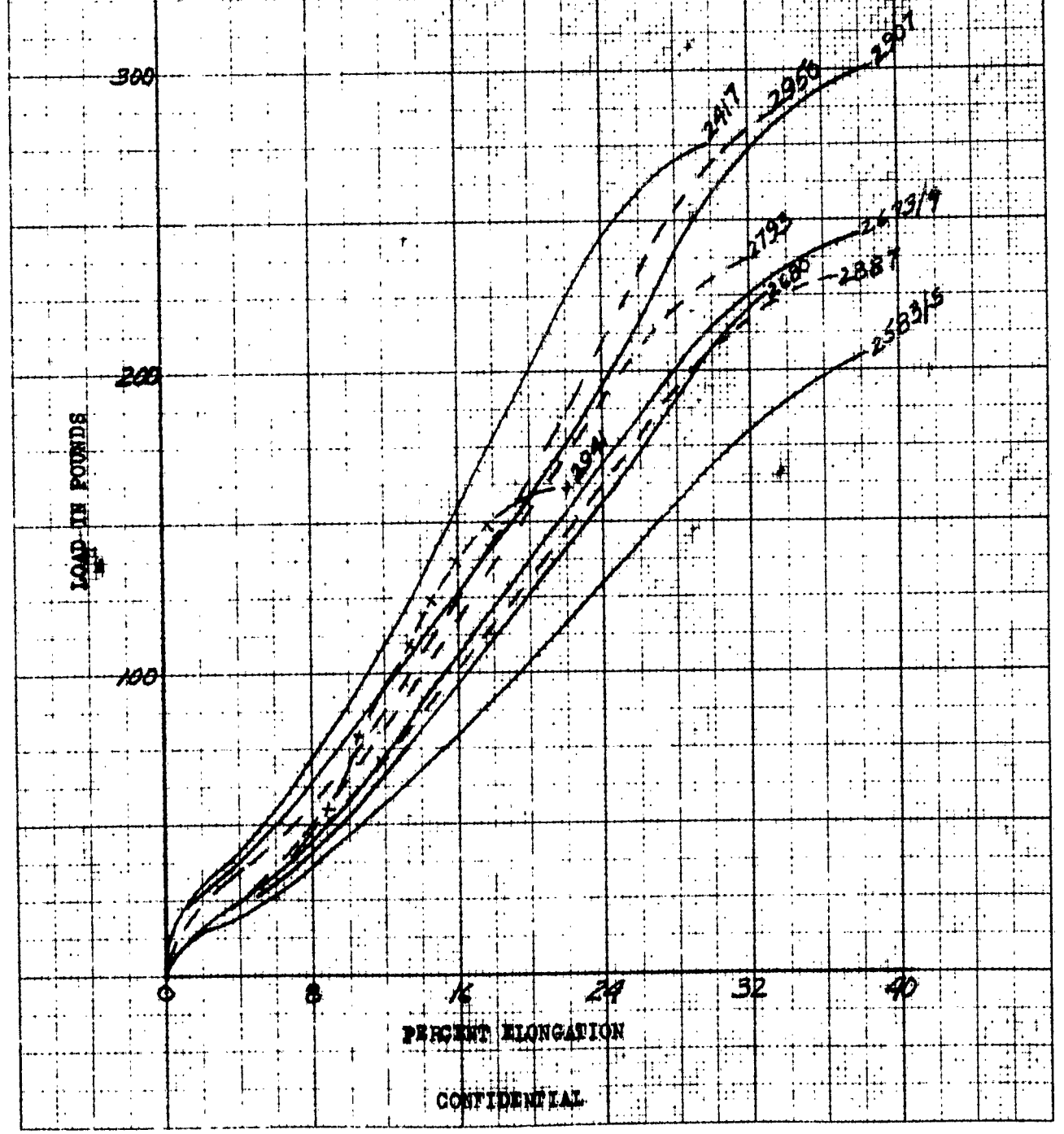
FIGURE 17
LOAD ELONGATION CURVES
OF NYLON FABRIC



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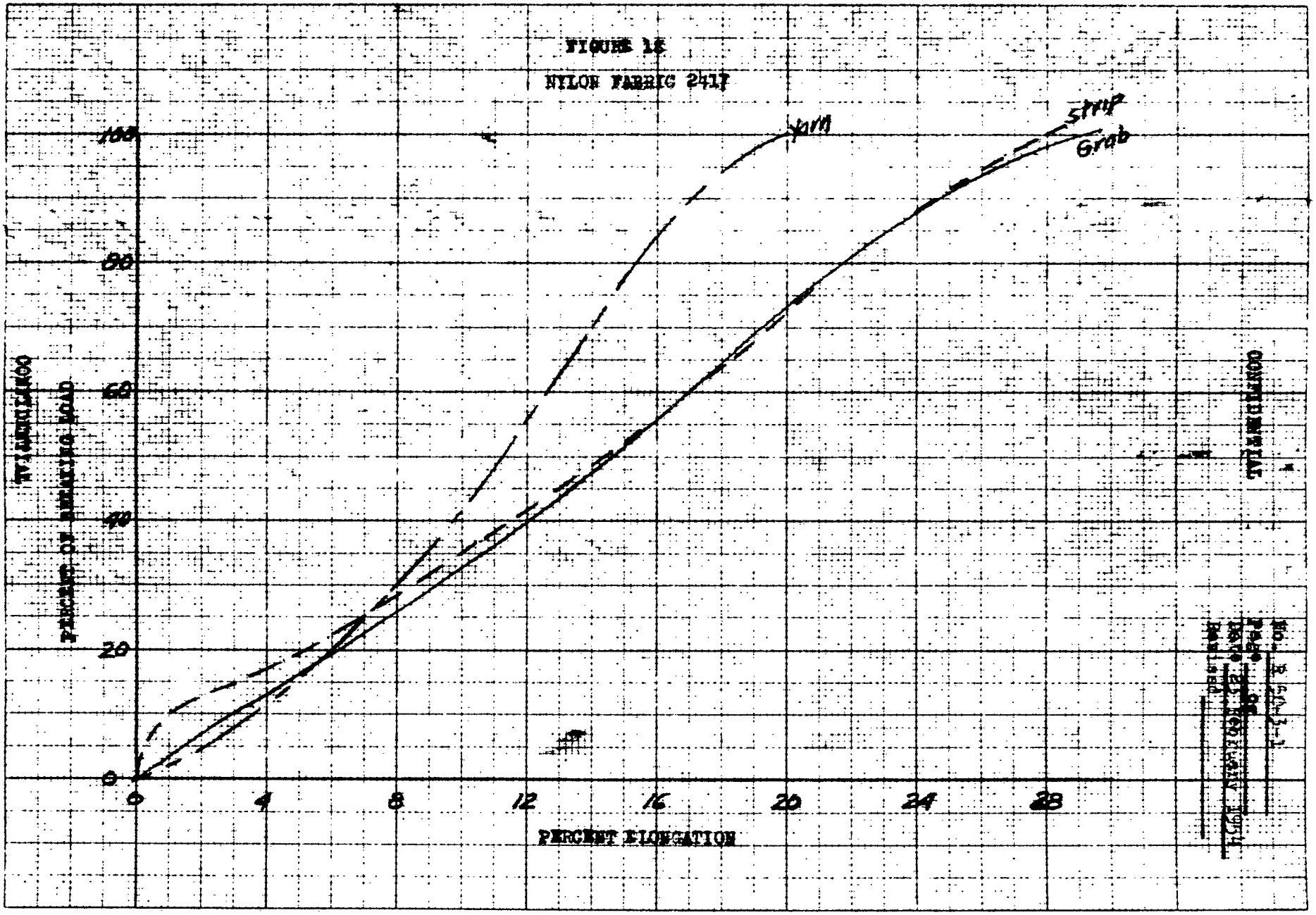

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FIGURE 19

NYLON FABRIC 8583/8

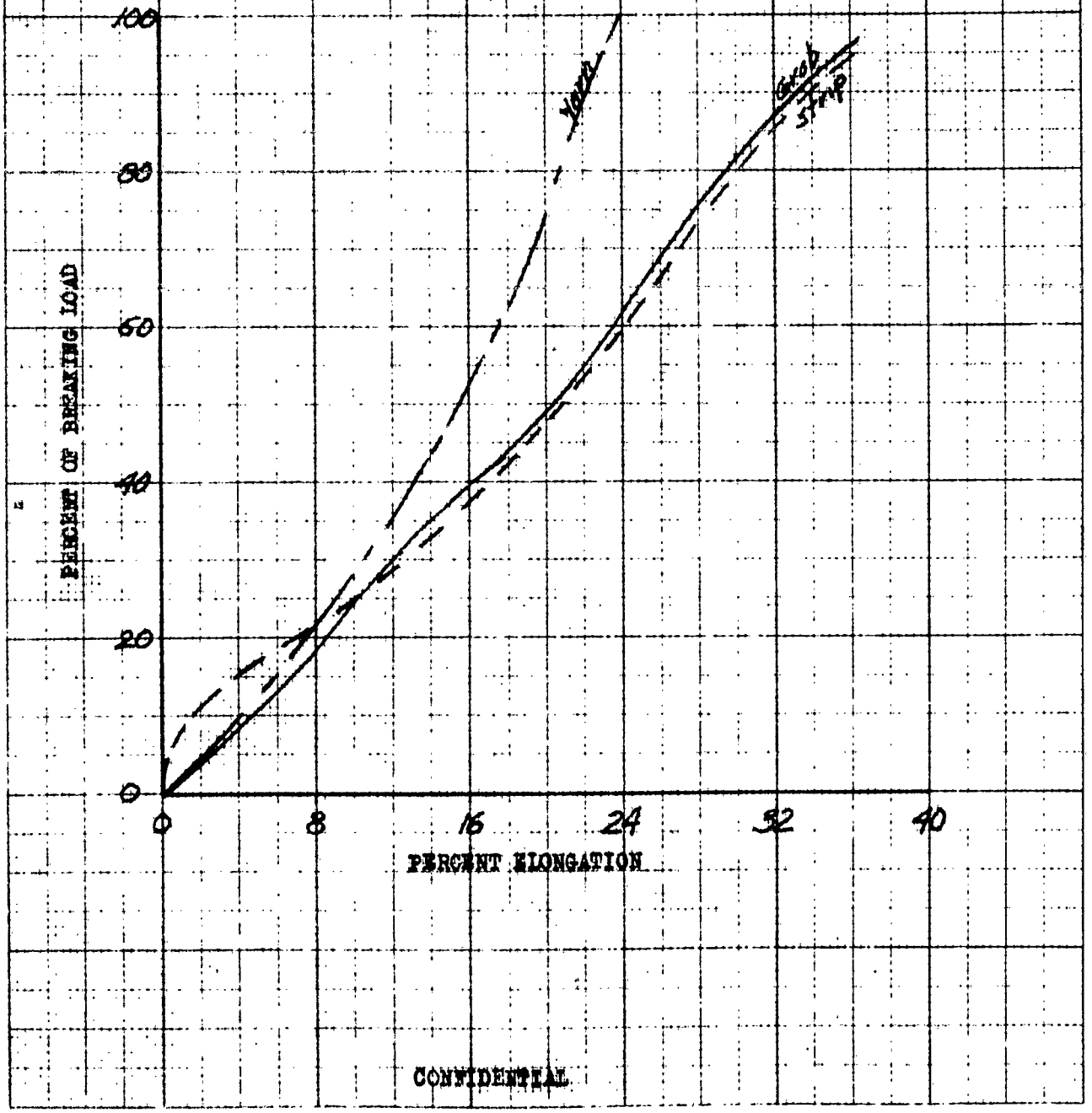

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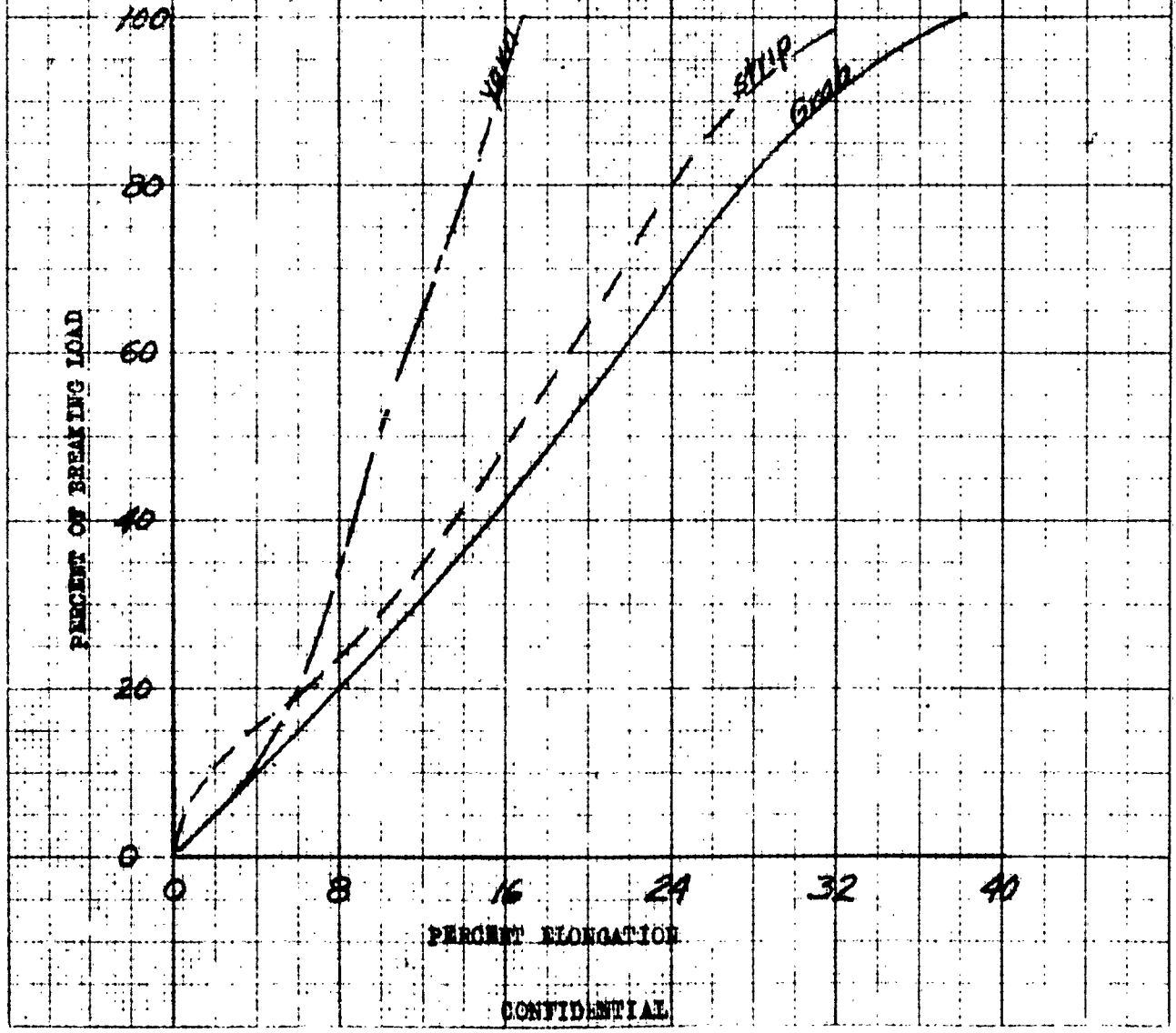
FIGURE 20

NYLON FABRIC 26T3/8



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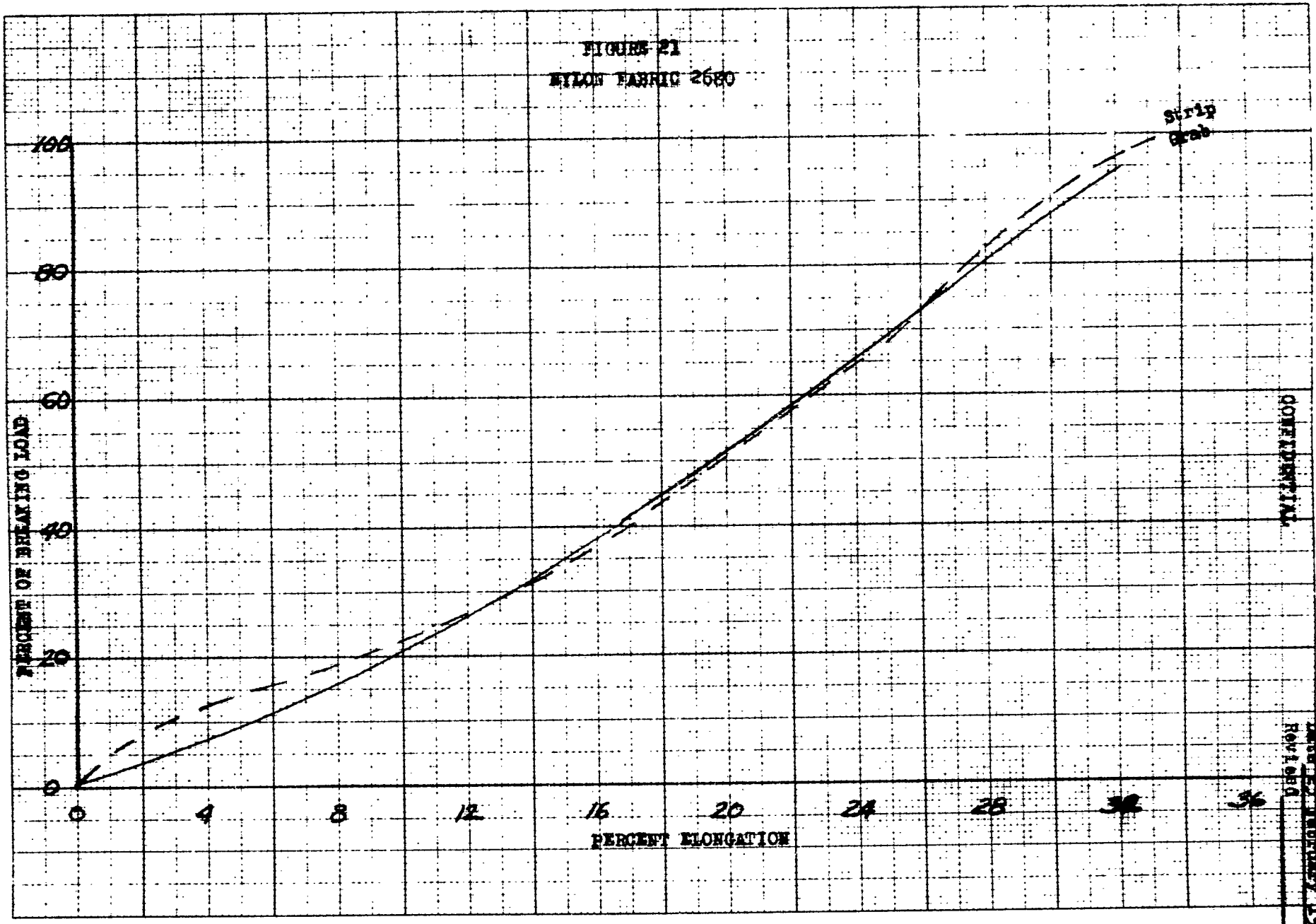

FIGURE 21
NYLON FABRIC 2680

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FIGURE 22

NYLON FABRIC 2793

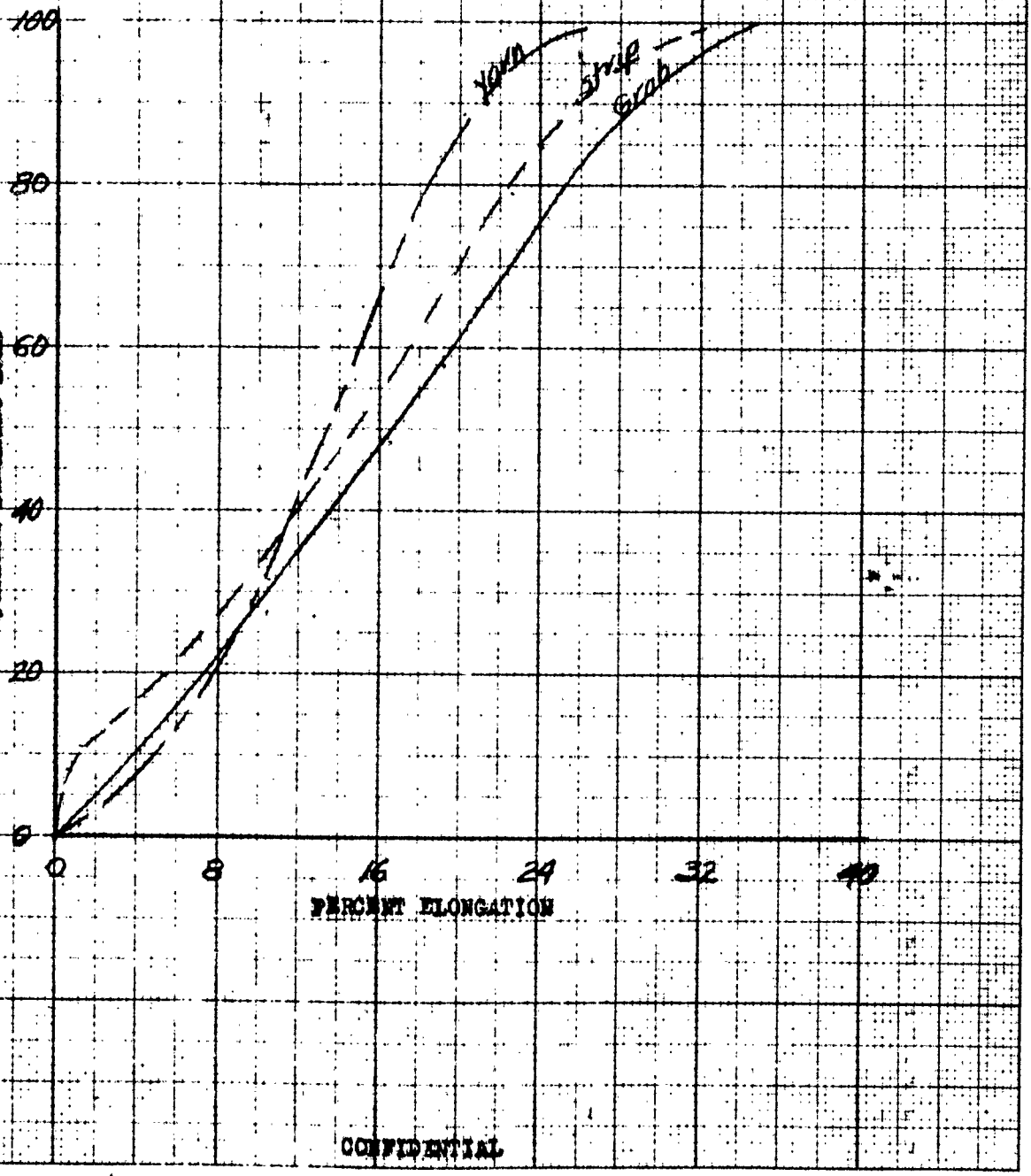

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FIGURE 23

NYLON FABRIC 2857

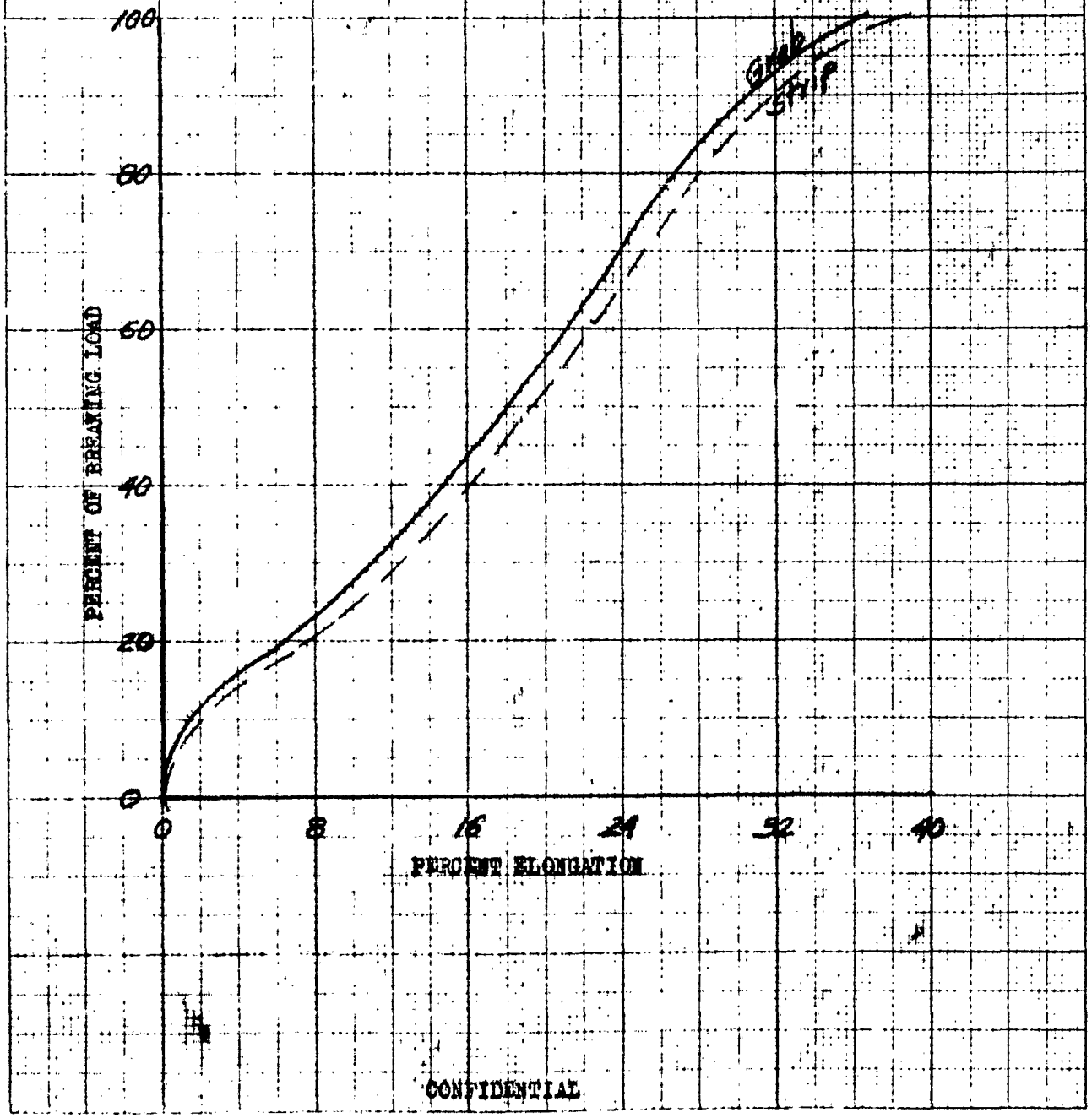

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FIGURE 24

NYLON FABRIC 2907

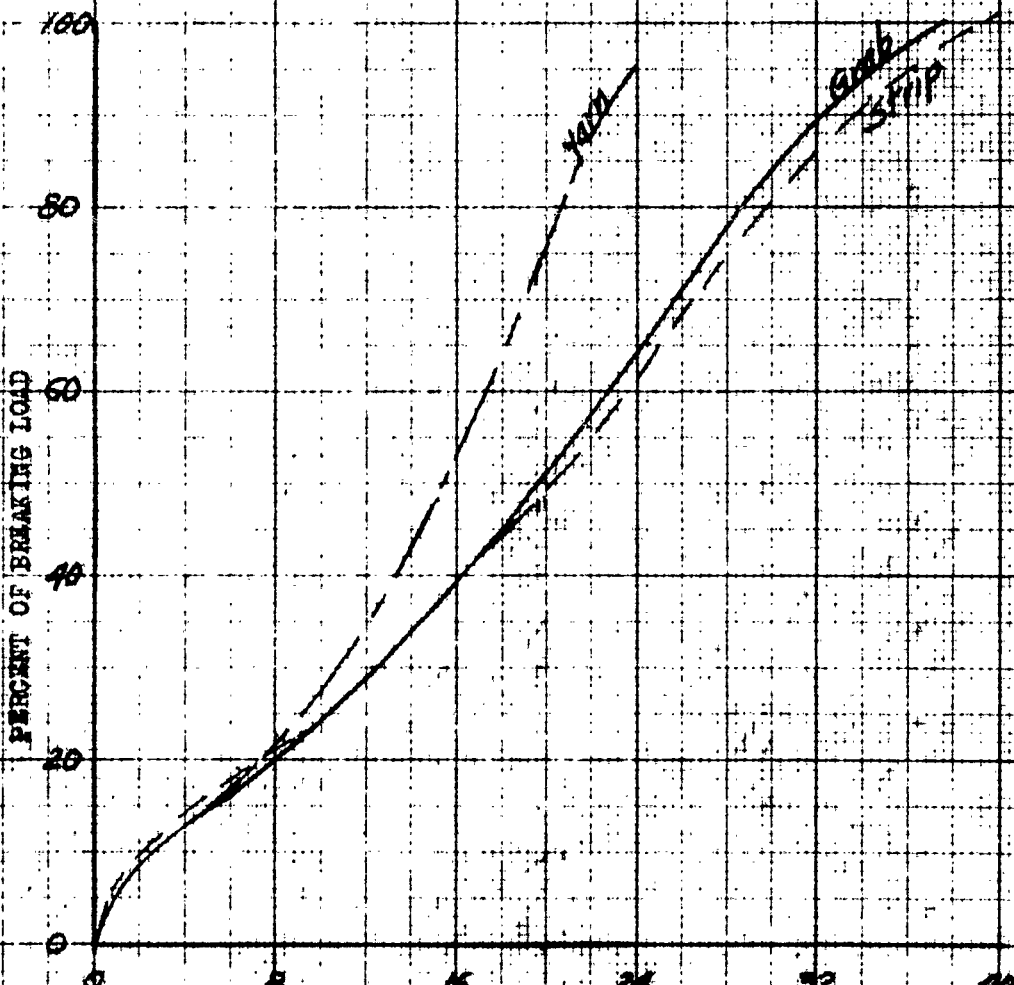

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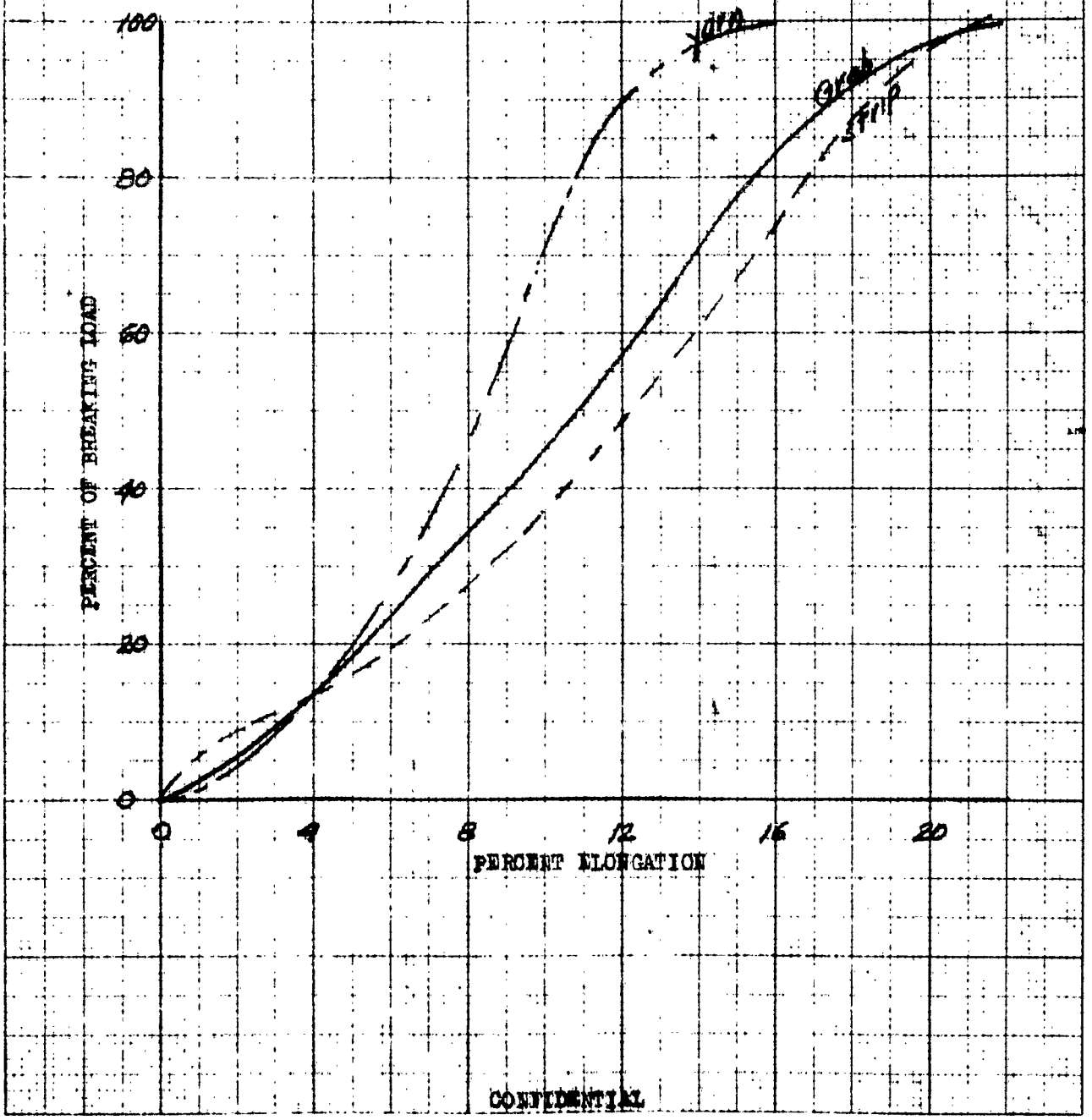
FIGURE 25

NYLON FABRIC 2491



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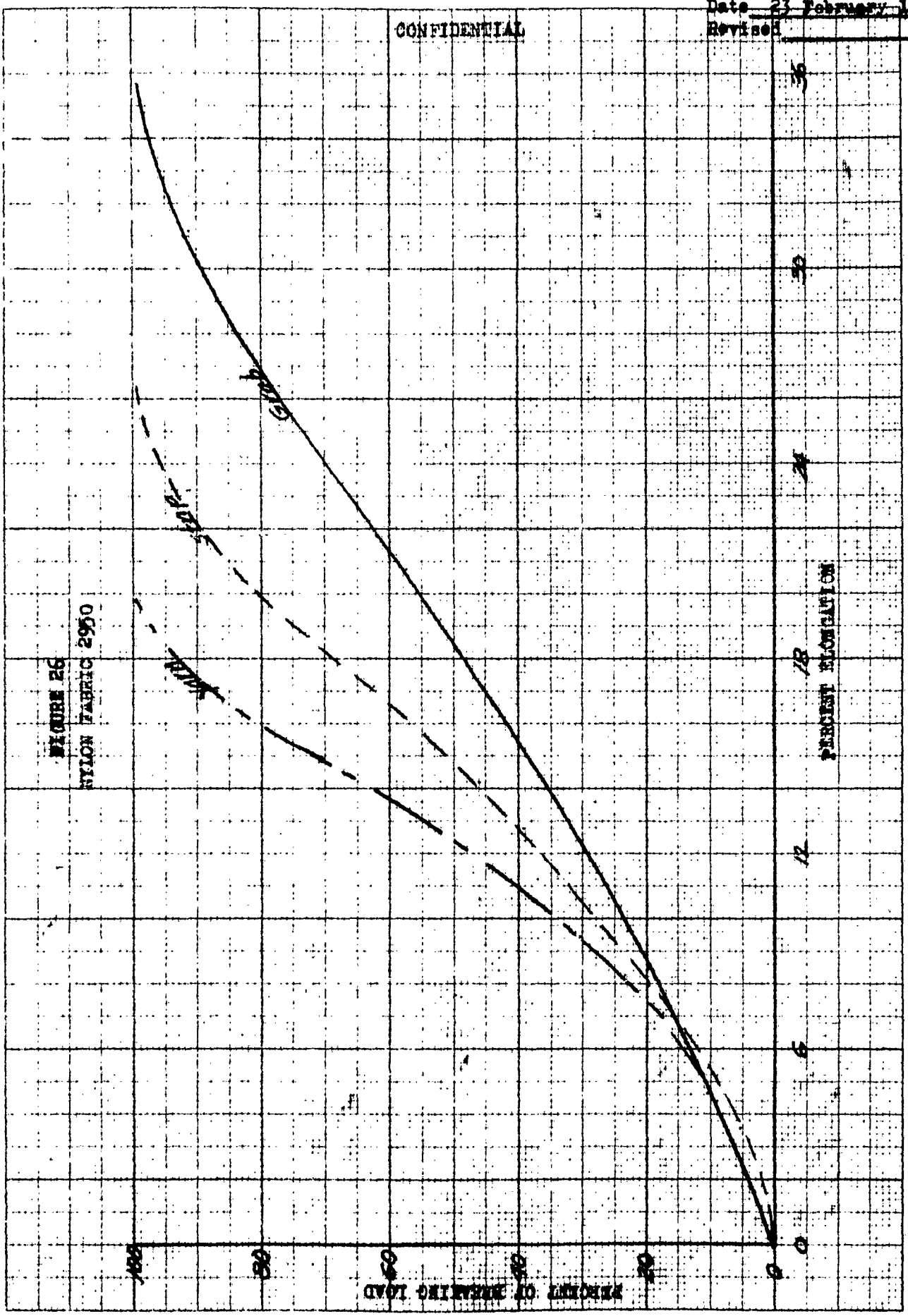

FIGURE 26
NYLON FABRIC 2950

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FIGURE 27
NYLON YARNS
210 DENIER 34 FILAMENTS
TYPE 300

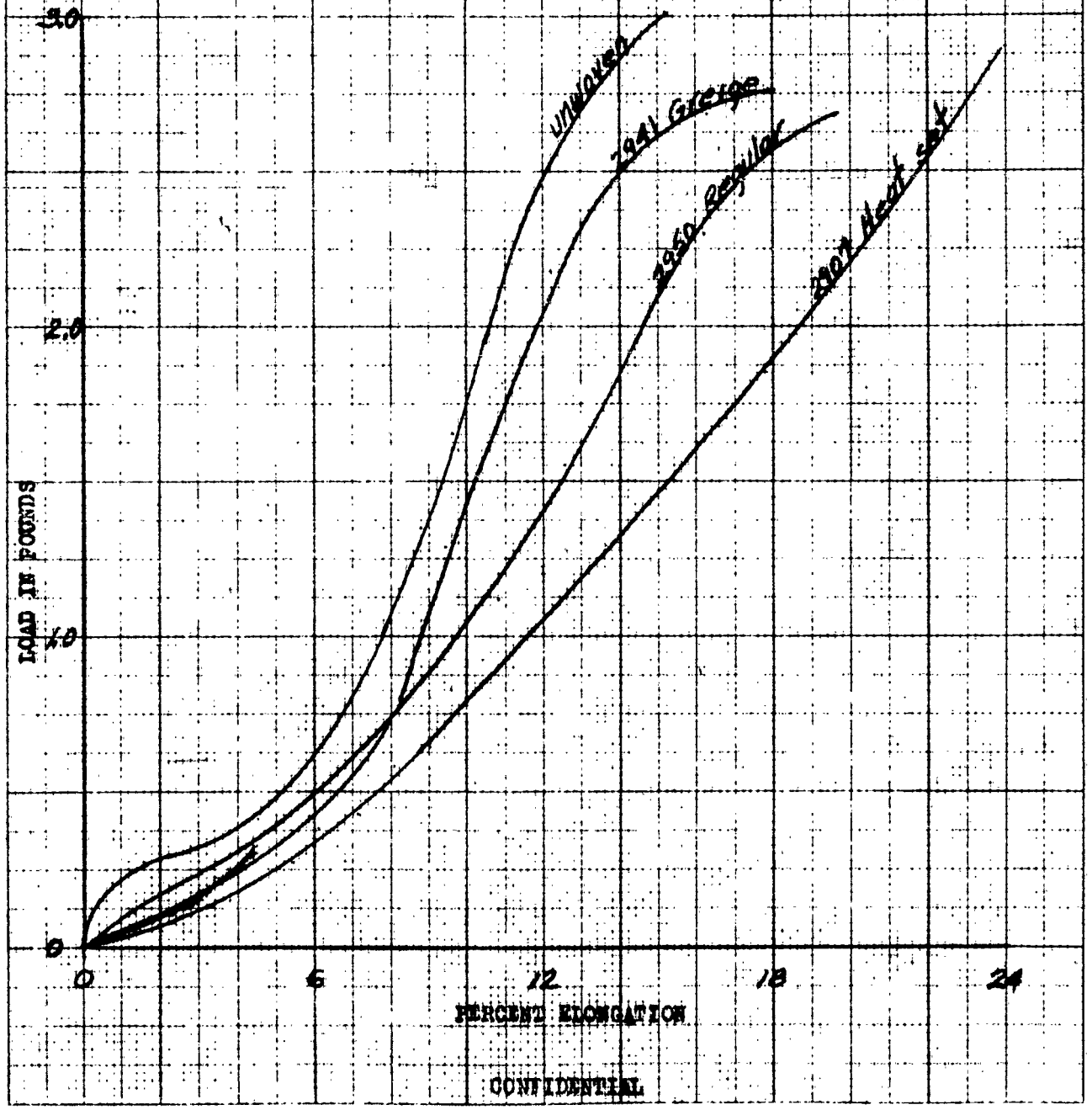

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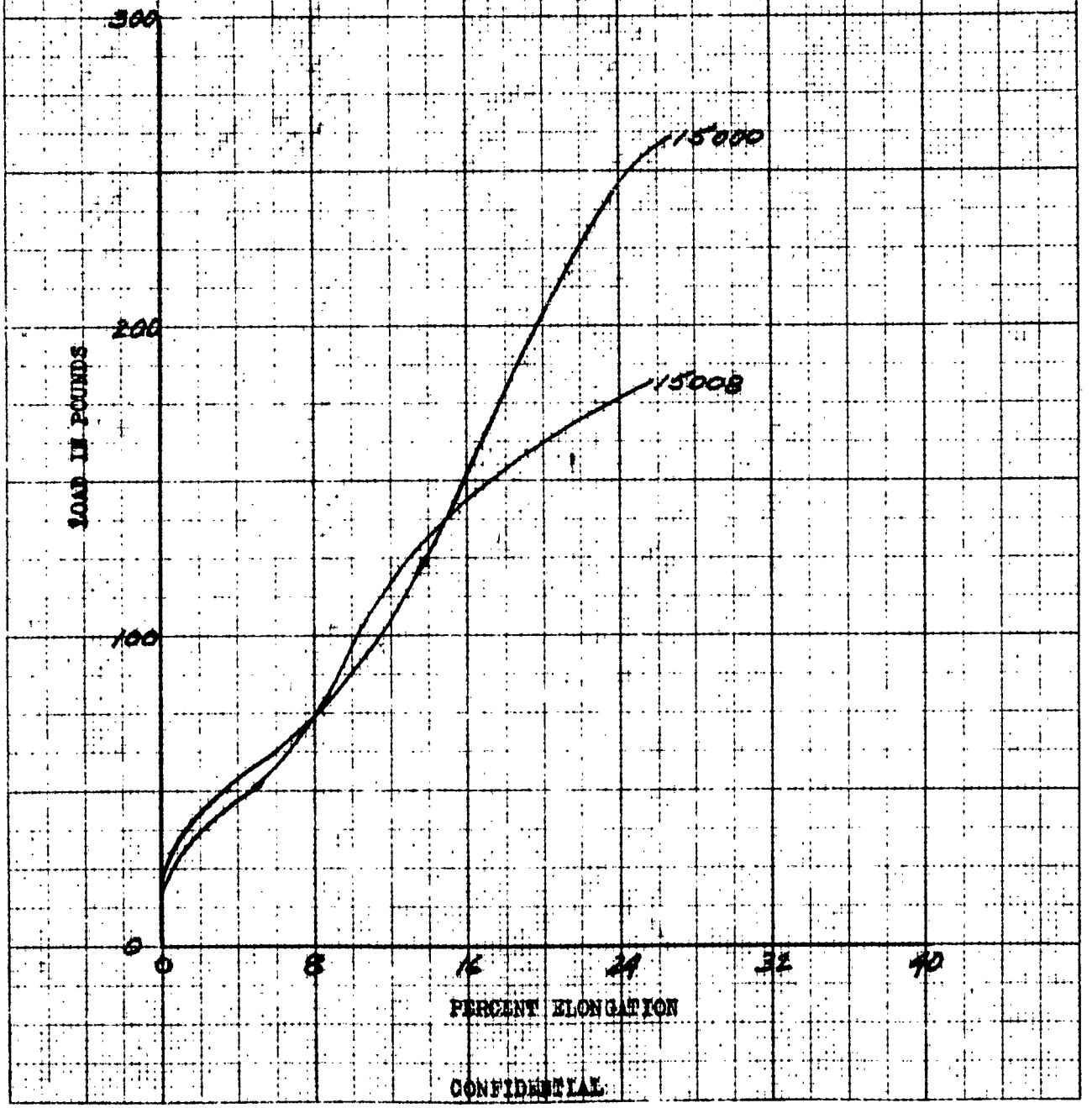
FIGURE P8

LOAD - ELONGATION CURVES ON DACRON FABRICS



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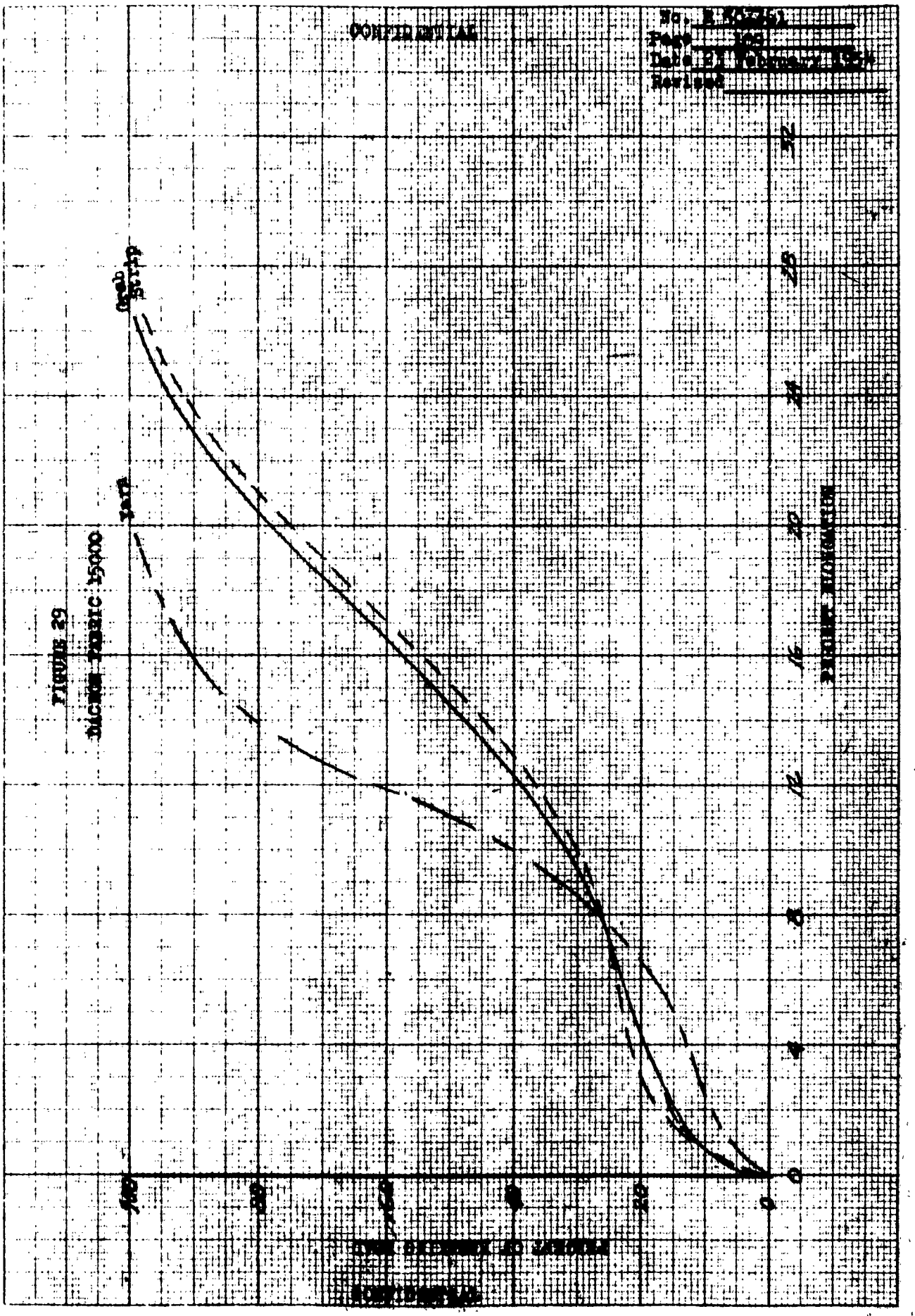

FIGURE 29
DACRON FABRIC 15000

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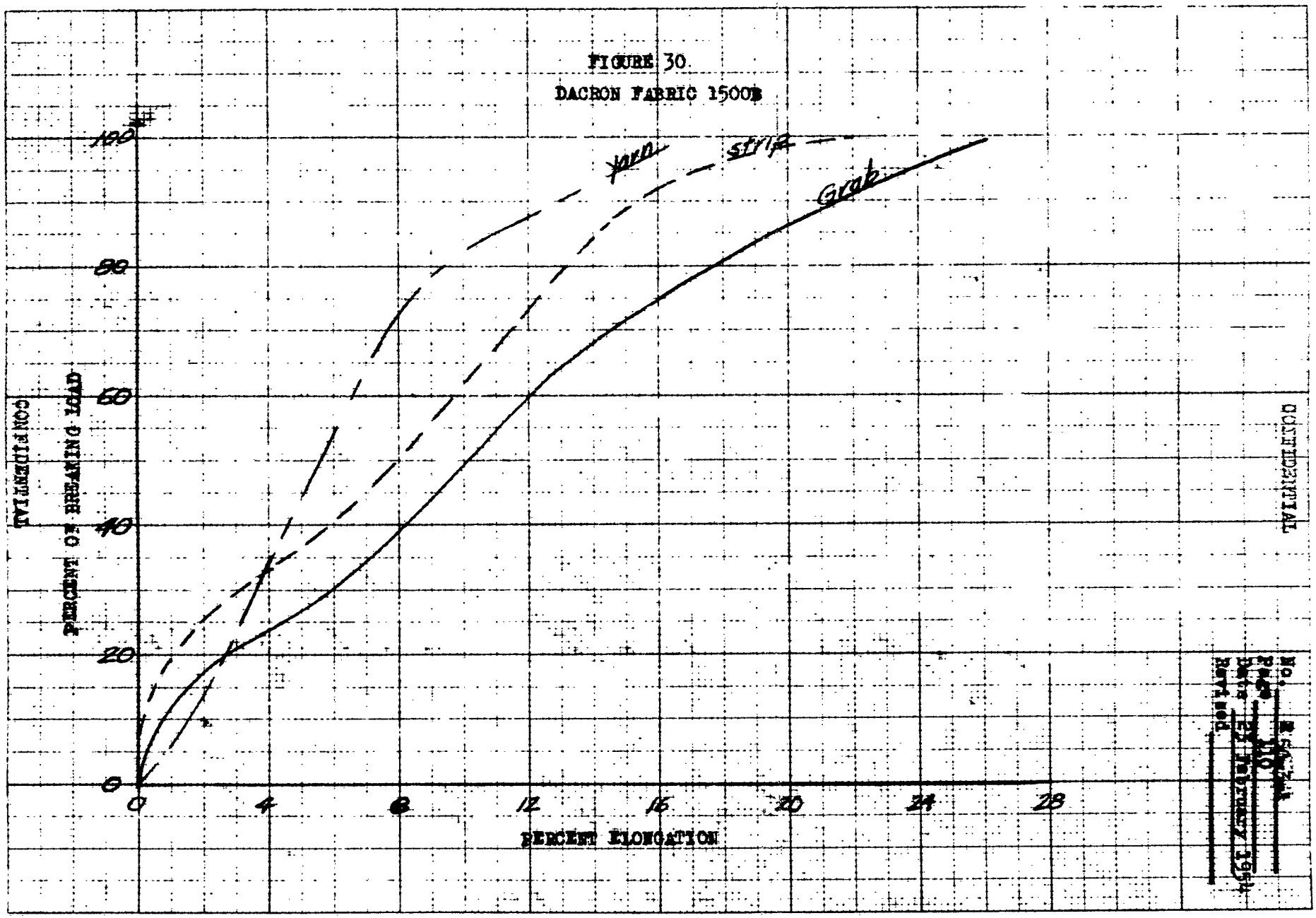

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FIGURE 31

LOAD - ELONGATION CURVES OF ORLON FABRICS

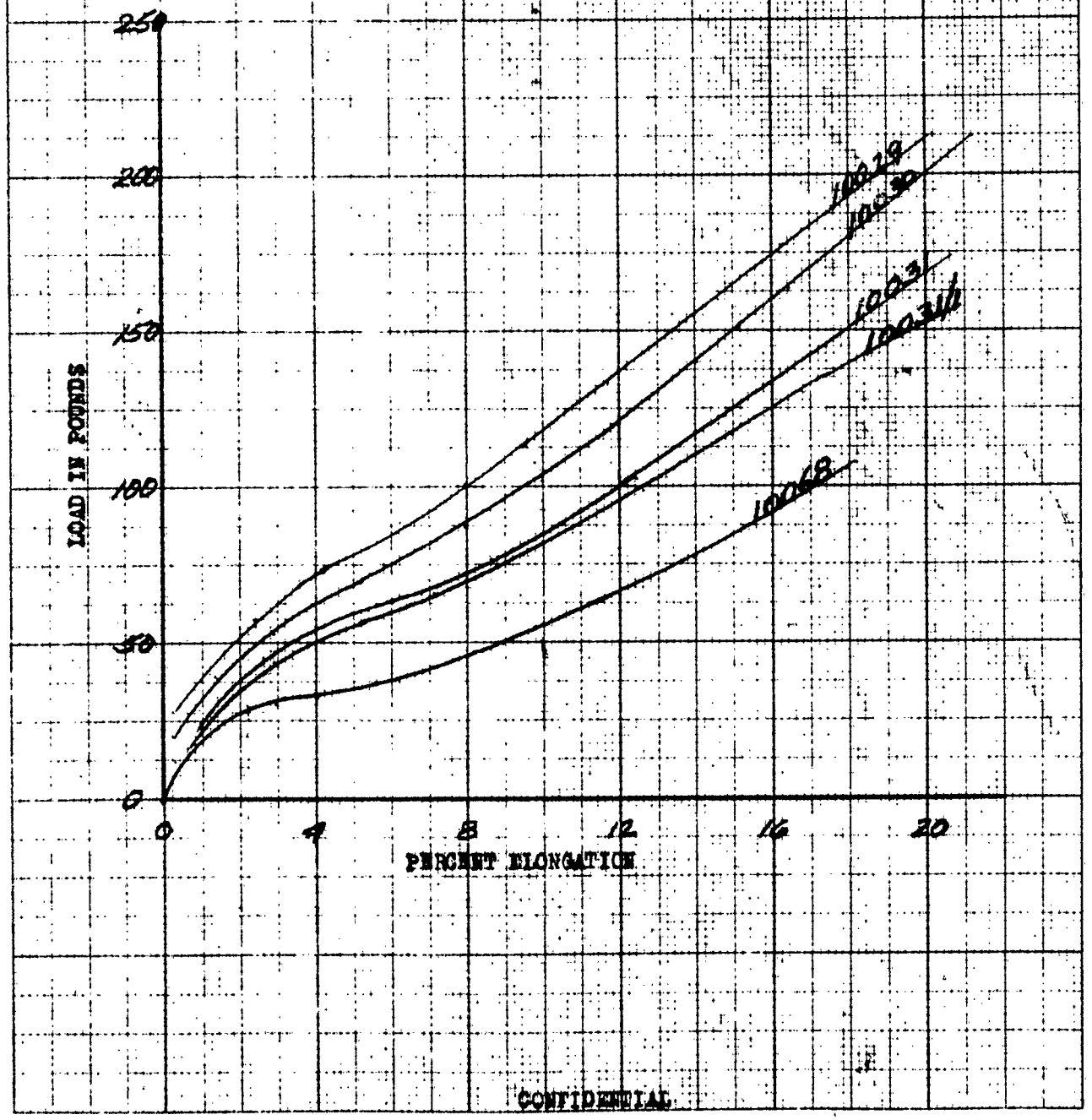

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FIGURE 32

ORLON FABRIC 10029

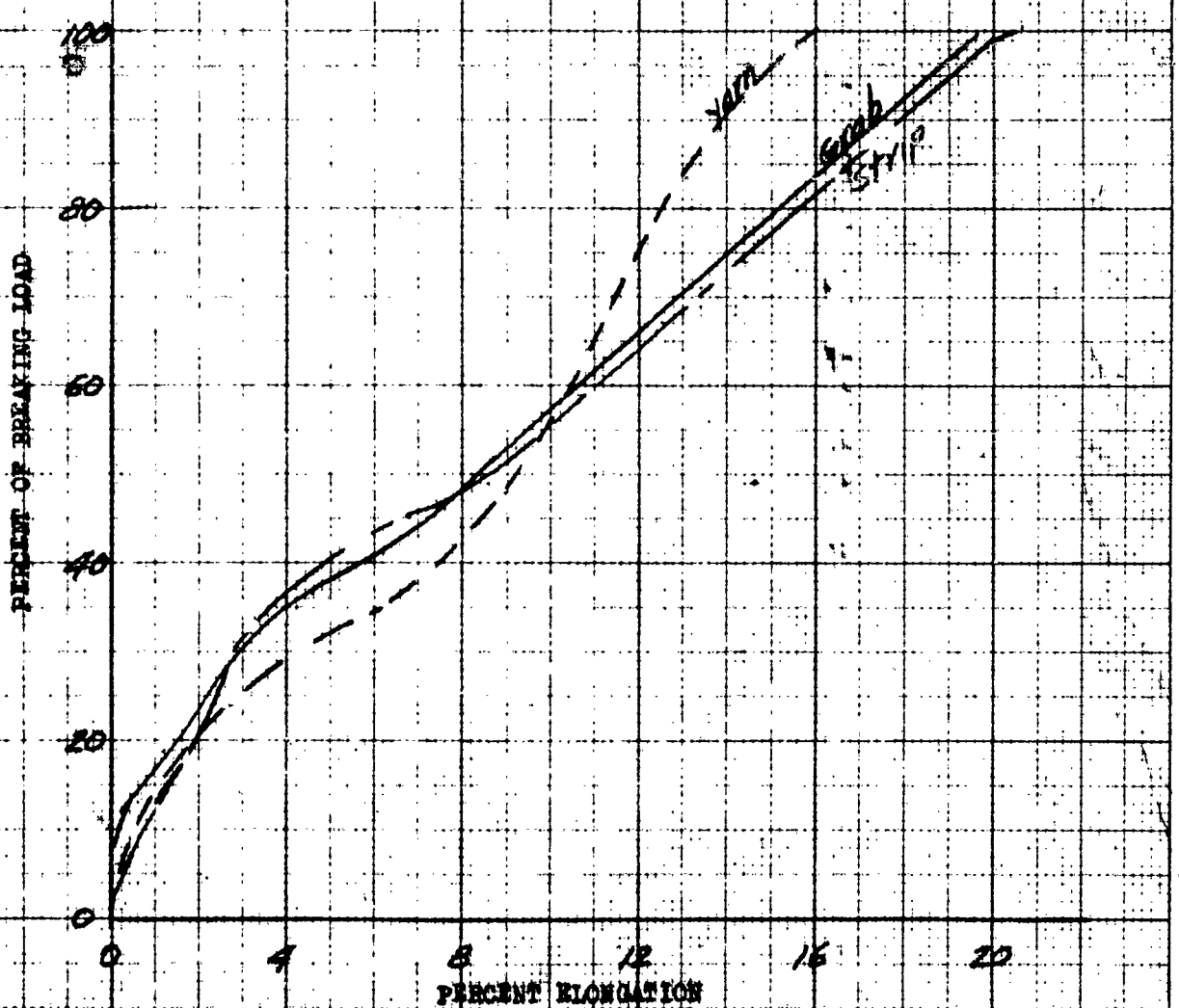

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FIGURE 33

ORLON FABRIC 10030

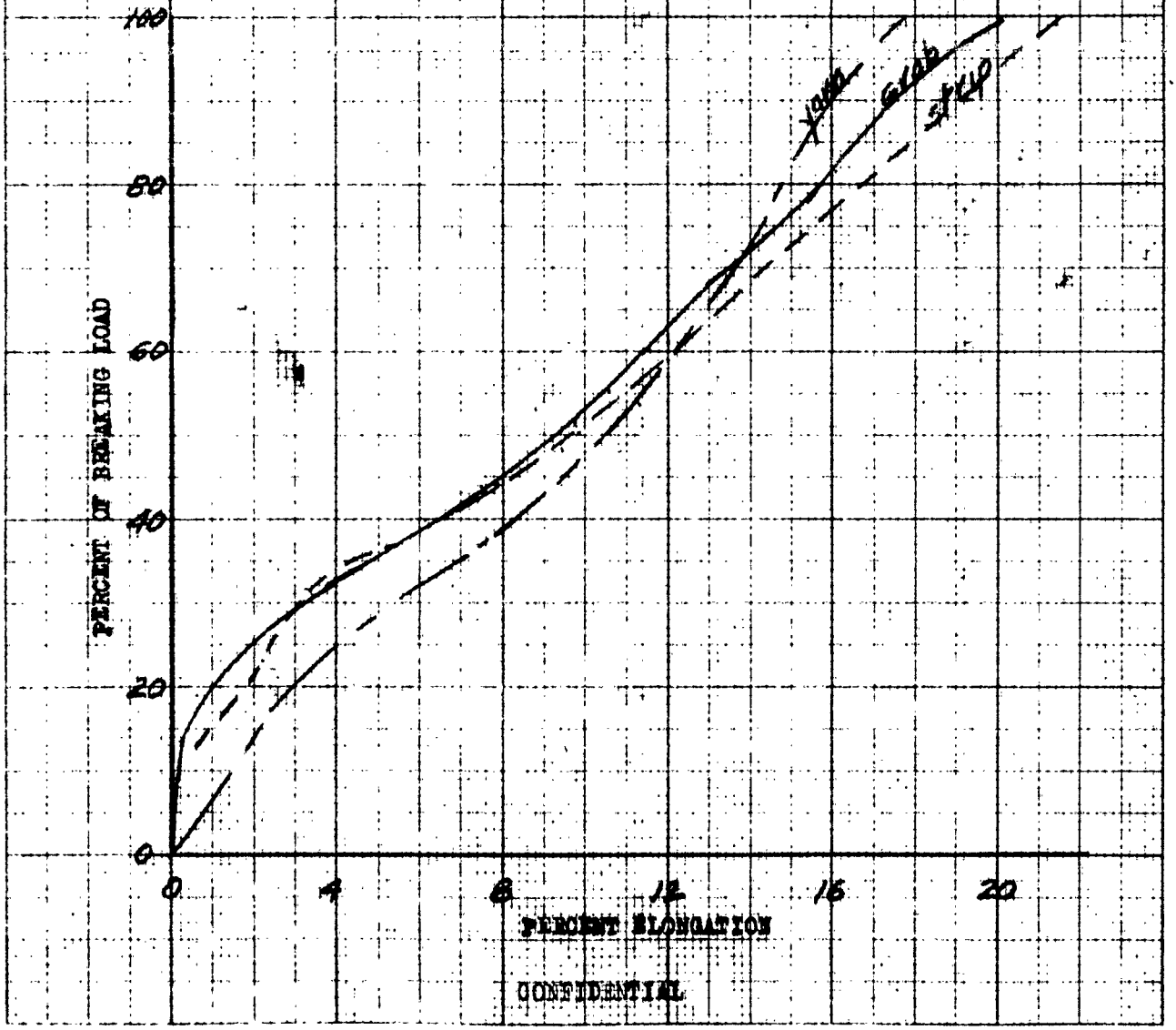

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FIGURE 34

ORLON FABRIC 10031

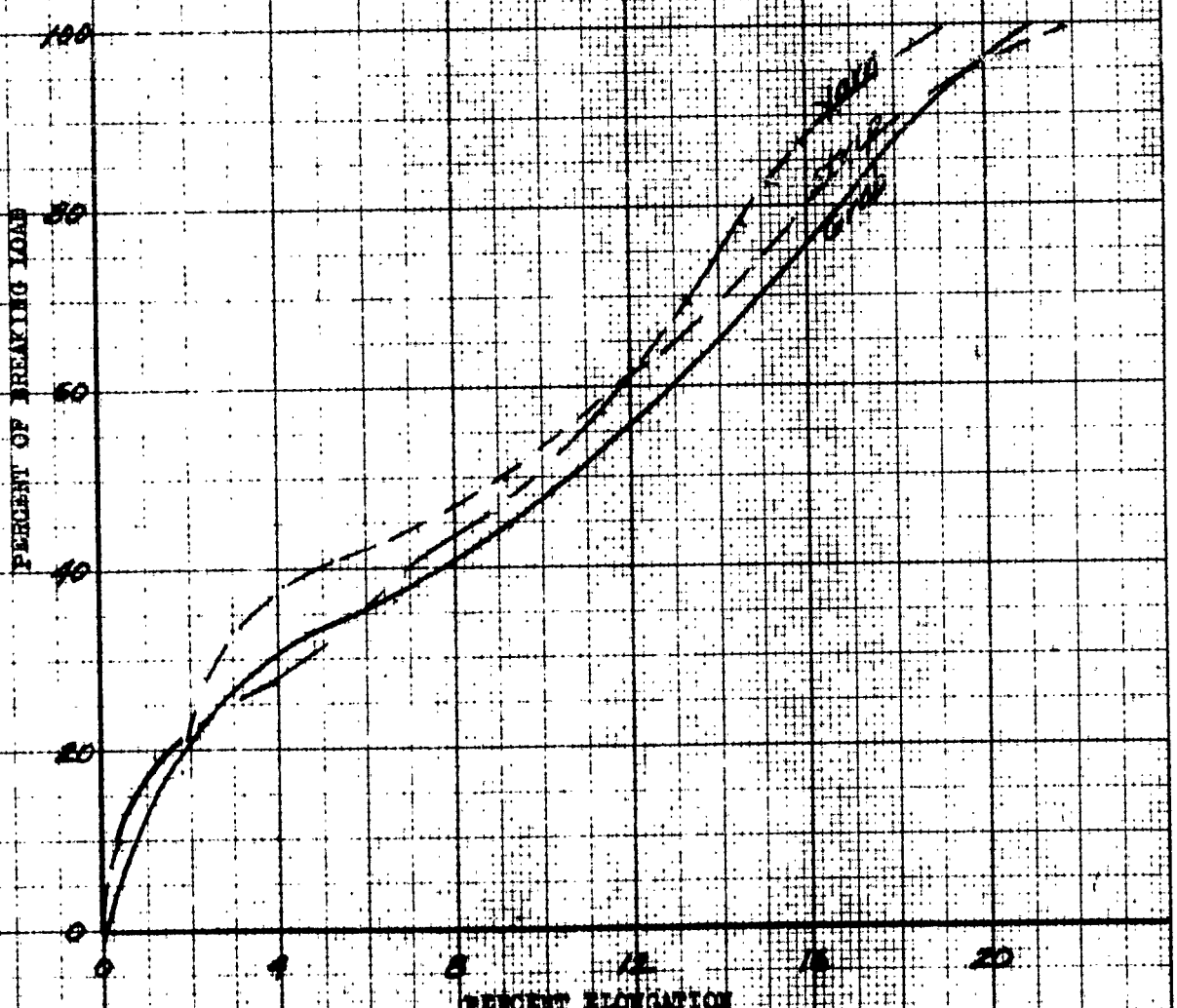

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FIGURE 35

ORLON FABRIC 10031/1

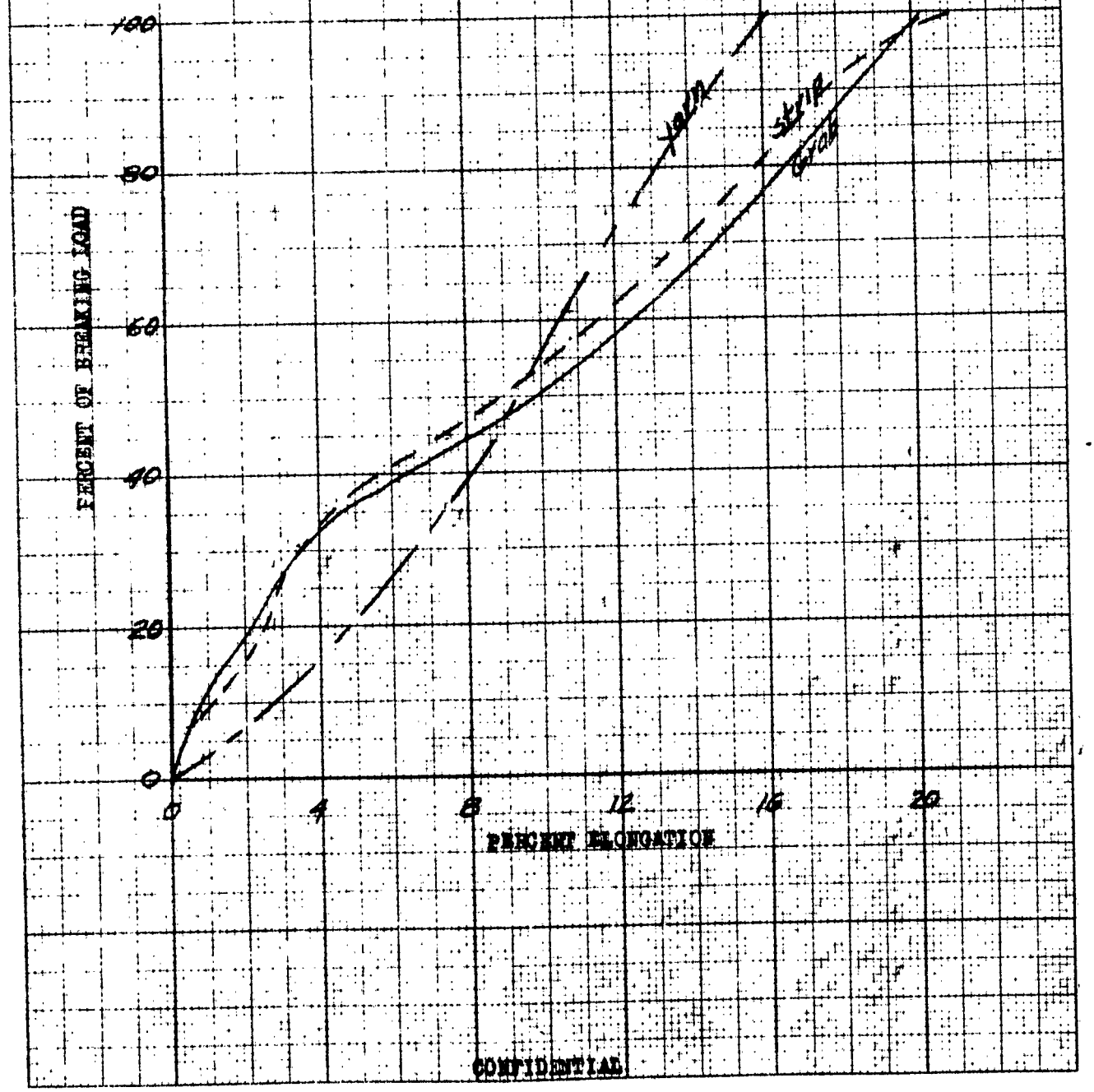

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FIGURE 36

OHLON FABRIC 10068

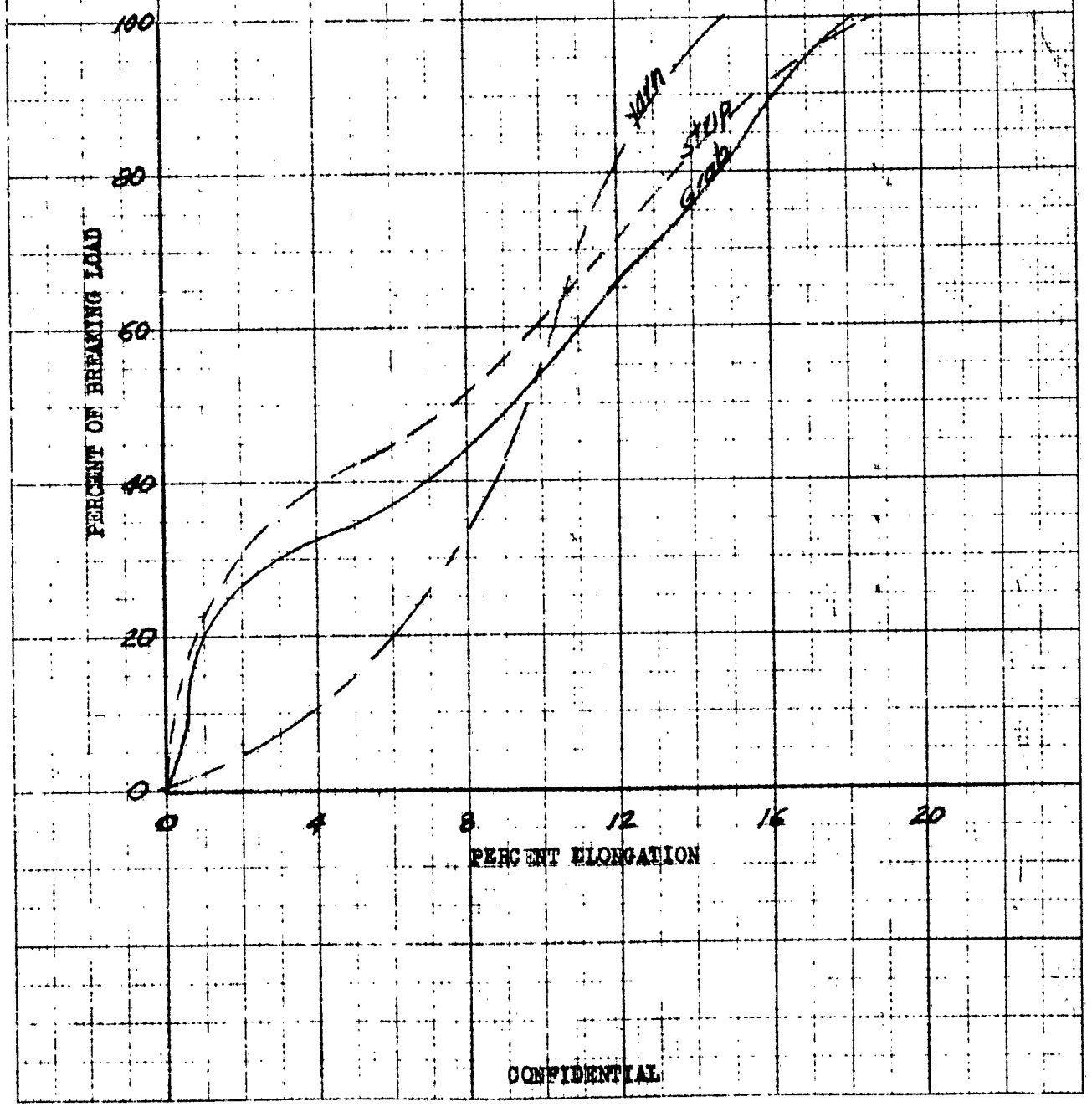

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FIGURE 37

LOAD - ELONGATION CURVES OF FORTISAN FABRICS

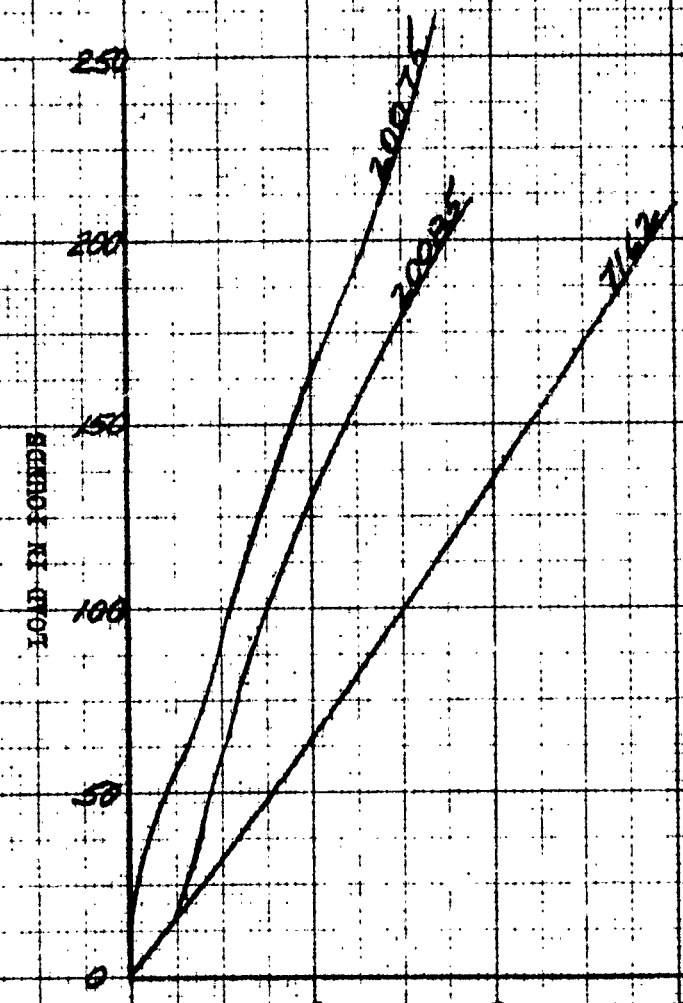

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FIGURE 38

FORTISAN FABRIC 7162

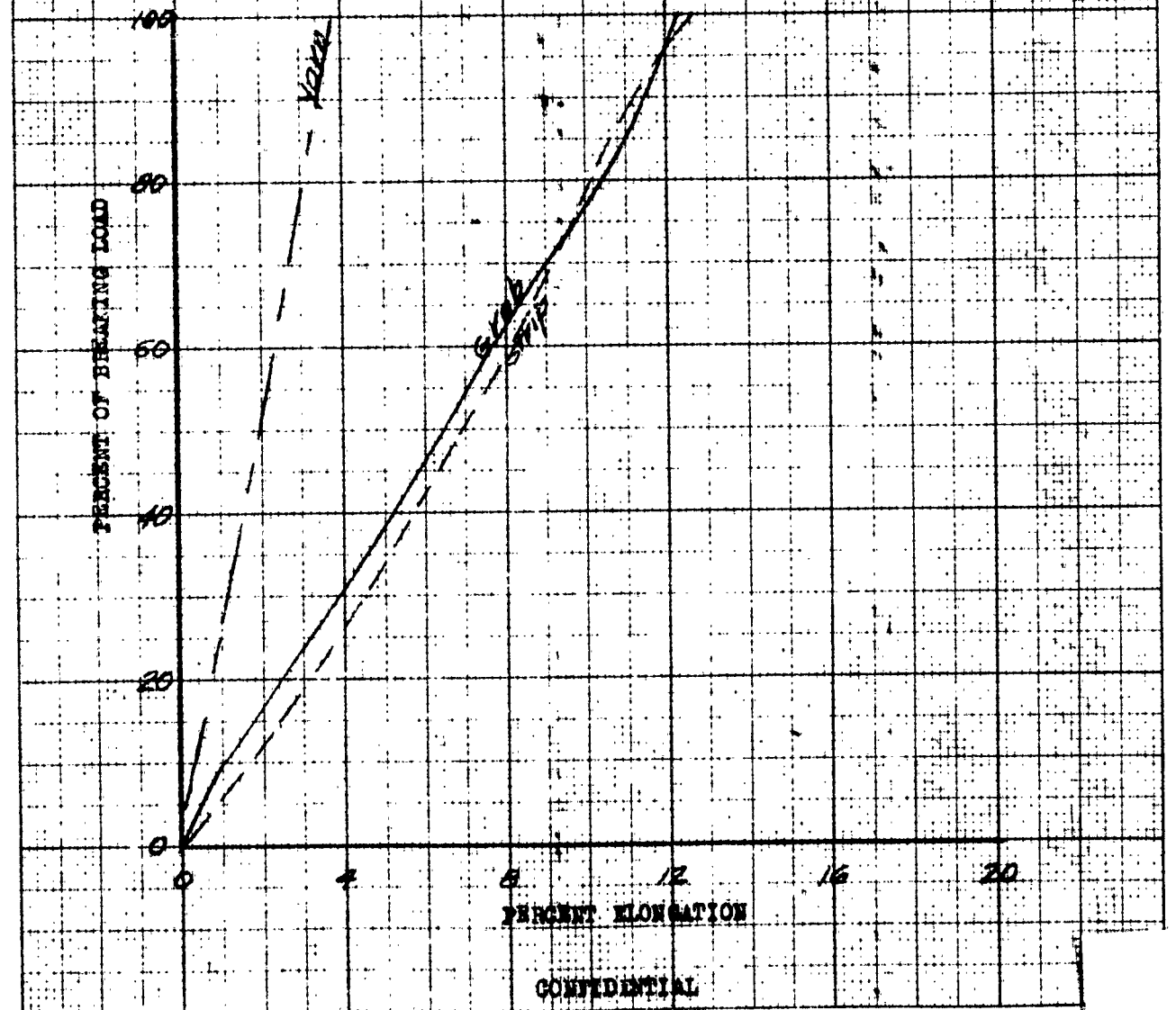

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FIGURE 39

FORTISAN FABRIC 20075

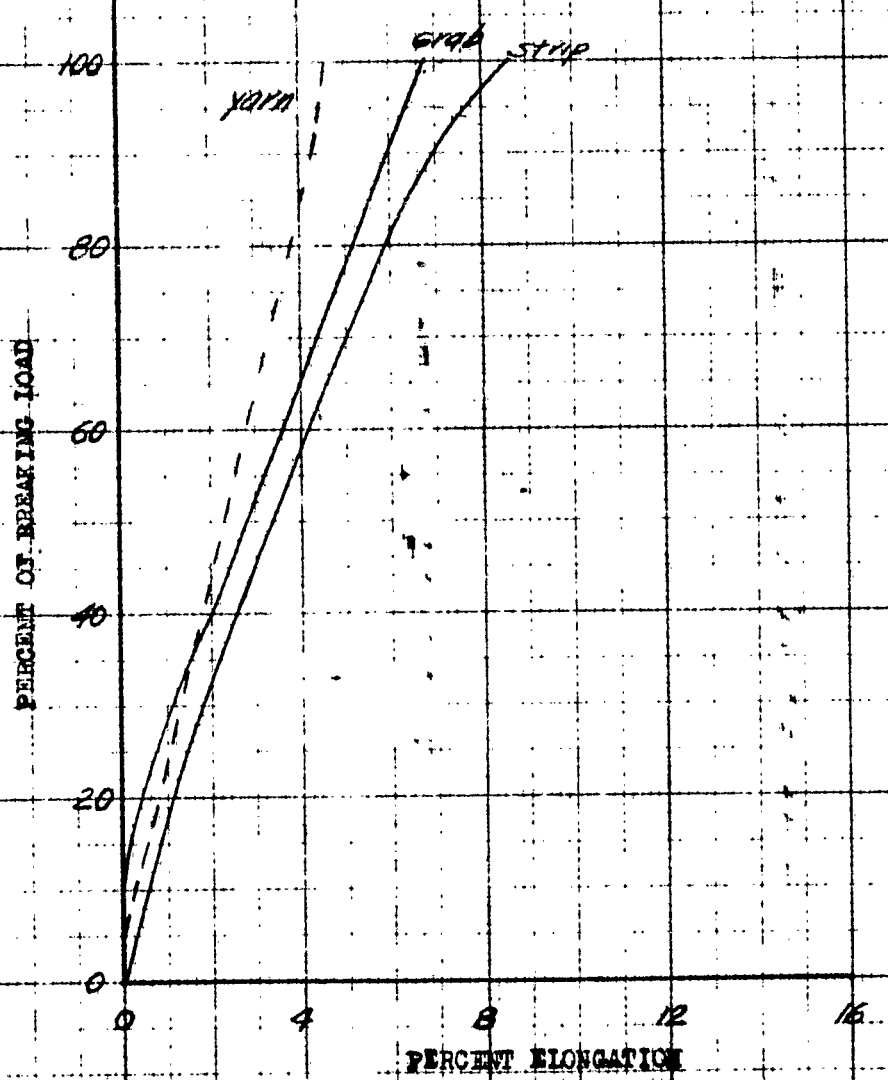

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FIGURE 40

FORTISAN FABRIC 20085

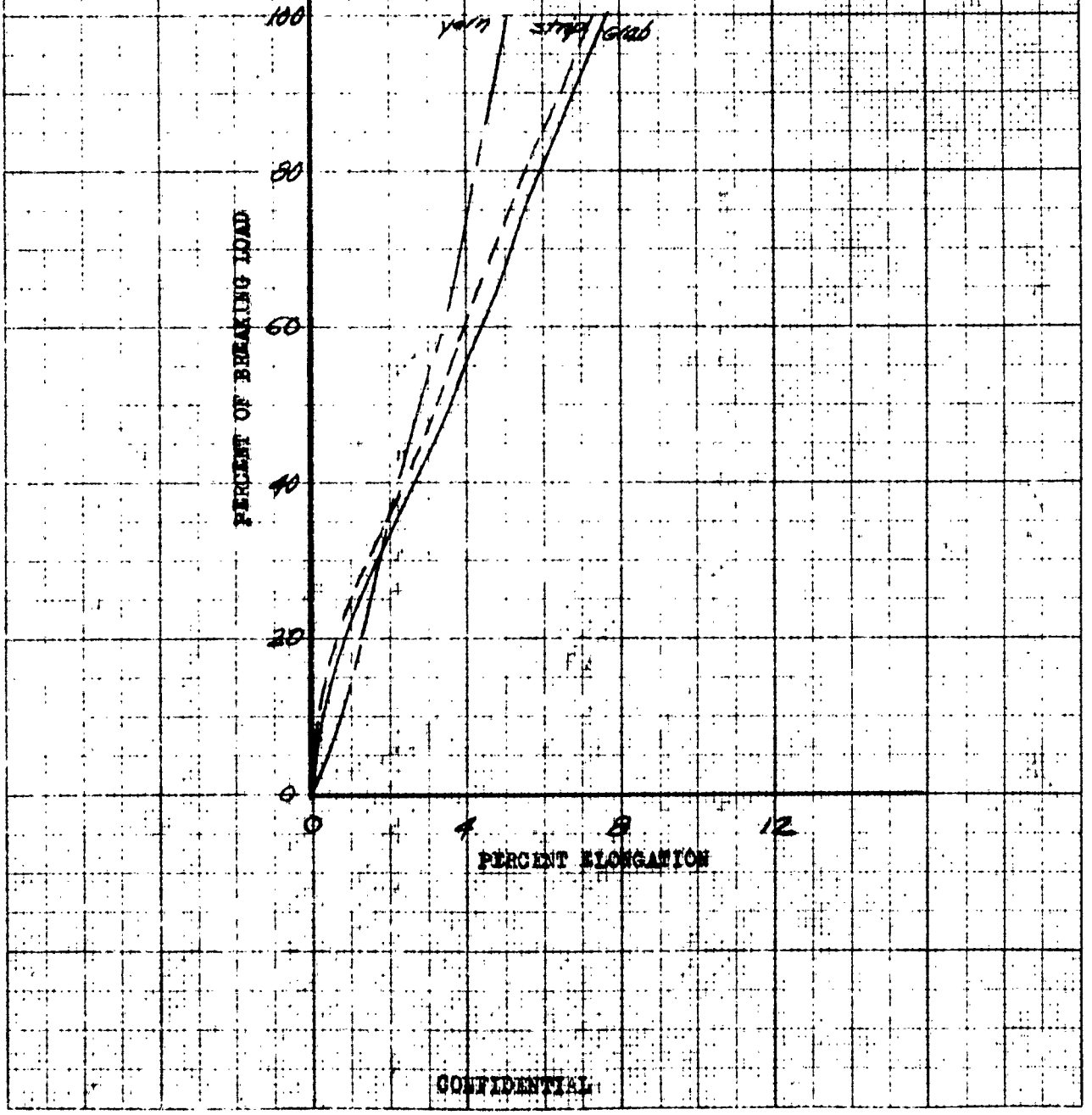

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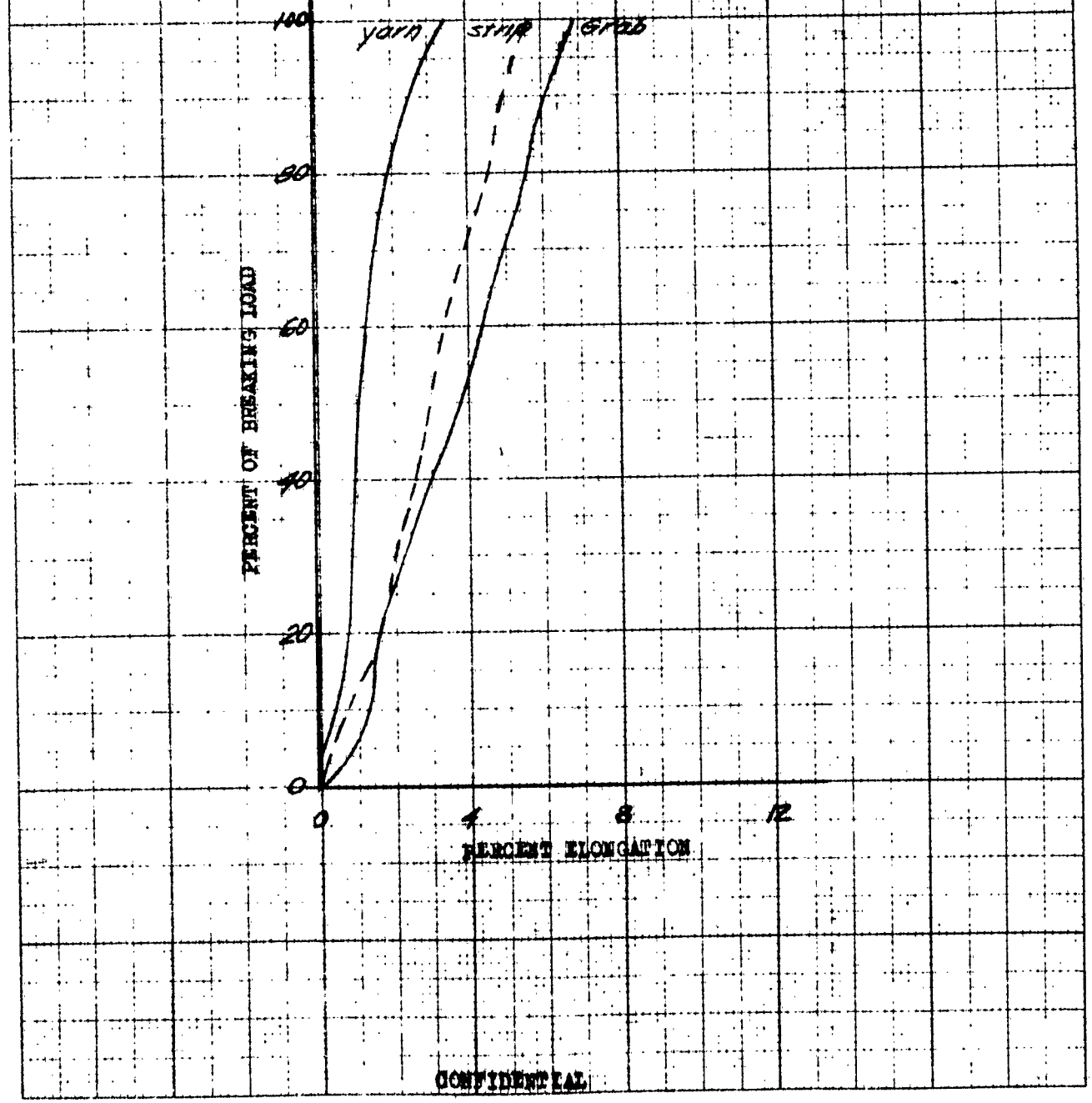
FIGURE 41

COTTON FABRIC 5013



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5.3.1.4 Strength-Weight Ratios

Included in Table XVII are calculated figures on strength-weight ratio, average stiffness and toughness index.

The strength-weight ratio is a rather arbitrary figure which enables comparisons to be made where fabric construction varies. This ratio is the ratio of the breaking strength in pounds per inch of fabric to the weight of the fabric expressed in pounds per square yard.

Nylon and Fortisan fabrics have the highest strength-weight ratios. The highest of these are for nylon fabrics. Dacron fabrics are the next strongest per unit weight, then Orlon and cotton. On the basis of these figures alone the weight of fabric in an airship envelope could be reduced to one-half or one-third that of cotton, and still have the same strength.

In Table XVII, average stiffness values are calculated as the breaking strength in pounds per inch of fabric divided by one-hundredth of the percent elongation. Fortisan fabrics have the highest stiffness, cotton has somewhat less stiffness, while Dacron, Orlon and nylon fabrics, on the average, fall within the same range of stiffness.

Toughness index values as listed in Table XVII are calculated as one-half the product of breaking strength in pounds per inch of fabric and one-hundredth of the percent elongation. This gives an approximation of the area under the load-elongation curve. Nylon fabrics are the toughest, then Dacron, Orlon, Fortisan, and cotton fabrics in decreasing order of toughness.

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TABLE XVII. CALCULATED MECHANICAL PROPERTIES OF TEST FABRICS

Fabric No.	Strength Weight Ratio		Average Stiffness		Toughness Index	
	Grab	Strip	Grab	Strip	Grab	Strip
2417	1055	800	936	733	40.1	28.7
2583/5	1073	783	543	388	39.9	29.6
2673/9	1316	945	637	530	45.9	28.7
2680	1110	690	682	420	37.1	23.3
2793	946	626	723	483	40.8	27.0
2887	1252	876	640	415	42.1	31.9
2907	1108	807	783	534	57.4	44.5
2941	1185	920	708	592	19.0	13.8
2950	1254	971	833	886	55.5	30.8
10,029	742	577	1092	813	20.8	16.8
10,030	769	649	948	800	21.0	17.6
10,031	678	536	875	648	17.5	15.0
10,031/1	642	505	740	740	19.6	16.4
10,068	593	528	612	500	9.2	9.0
15,000	972	700	967	681	34.0	24.8
15,008	843	586	715	717	24.1	11.6
7162	1152	896	1750	1302	12.6	10.3
20,075	928	872	3890	2952	8.7	10.3
20,085	1041	900	3210	2810	7.2	7.4
5013	414	425	1885	2956	4.6	3.1

5.3.1.5 Tear Tests

It had been suggested that a tear test carried out by making a cut in the fabric and then applying stress at right angles to it, would simulate conditions in an airship envelope much more closely than a tongue tear test.

Some experiments on such a cut tear test were carried out with RR balloon cloth (cotton fabric 5013), and it was found that the fabric pulled apart instead of tearing. If one square yard or more could be used, then the fabric probably would tear because the yarns would not slip readily. It was decided that the yarns would have to be held in position in order to get a reliable test on a reasonably sized sample such as a four by six inch piece of fabric.

Accordingly, a series of four by six inch samples was prepared in which the area coated varied from just the edges to all except a quarter inch strip across the center of the sample. In all cases the center strip, which contained a 1.5 inch cut across the warp yarns, was not coated on the edges. The coating used was a mixture of equal parts of Vinylite VYNS and Acryloid A-101. The samples were placed in a Scott tensile tester in the same manner as the normal grab tensile specimen using one inch jaws. As load was applied to the sample it tore across the warp yarns, starting at the edges of the cut. The tear curve was recorded and the tearing strength in pounds determined as the average of the five highest peaks of the curve. It was found that tear strength increased with decrease in amount of coating, the sample with the edges coated having the highest strength and probably giving the closest approximation to

an uncoated sample.

Another series was then carried out on edge-coated samples using a different length of cut. For cuts less than one inch long, the first yarns had to be broken by direct tensile pull before tear occurred. A cut one and one-quarter inches long was decided upon as the standard.

The tear tests developed, then, consists of coating the edges of a 4 x 6 inch fabric sample one-quarter to three-eighths inches wide with a combination of equal parts of Vinylite VYNS and Acryloid A-101 from a methyl ethyl ketone solution. The sample is dried in an oven at 180° F. for five minutes. A cut with a razor blade is then made across the center of the samples at right angles to the longest dimension. The tear test is run in a Scott tensile tester using one inch jaws. Tear strength is determined as the average load in pounds of the five highest peaks of the recorded tear curve. A sample is illustrated in Figure 42.

Tear strengths of all the test fabrics are given in Table XVIII. Tongue tear results are given as determined by the manufacturer of the fabric.

The open weave fabrics such as basket weaves and the mock leno weave are harder to tear than others. In the Orlon series, tear strength increases with the number of plies in the basket weave. In the nylon series, the fabrics made from the lower denier yarns tear somewhat more easily. This may be because of the nature of the weave or because in a tear test

one yarn at a time is broken and it is easier to break the weaker yarns.

Tear strength-weight ratios were calculated by dividing the cut tear strength in pounds by the weight of the fabric in pounds per square yard. Perhaps the only significant change in order of strength is that nylon fabric 2941 has quite a high ratio.

The cotton fabric and the Fortisan fabrics have relatively low tear strengths and tear strength-weight ratios. Certain nylon fabrics (2793, 2941, and 2950) have high ratios. More work is planned with the latter two fabrics. Sample 2793 has the lowest tensile strength-weight ratio of all the nylon fabrics, so no more work will be done with it at the present time.

Orlon values, on the average, are between those of nylon and Dacron.

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FIGURE 42
FABRIC TEAR TEST SAMPLE

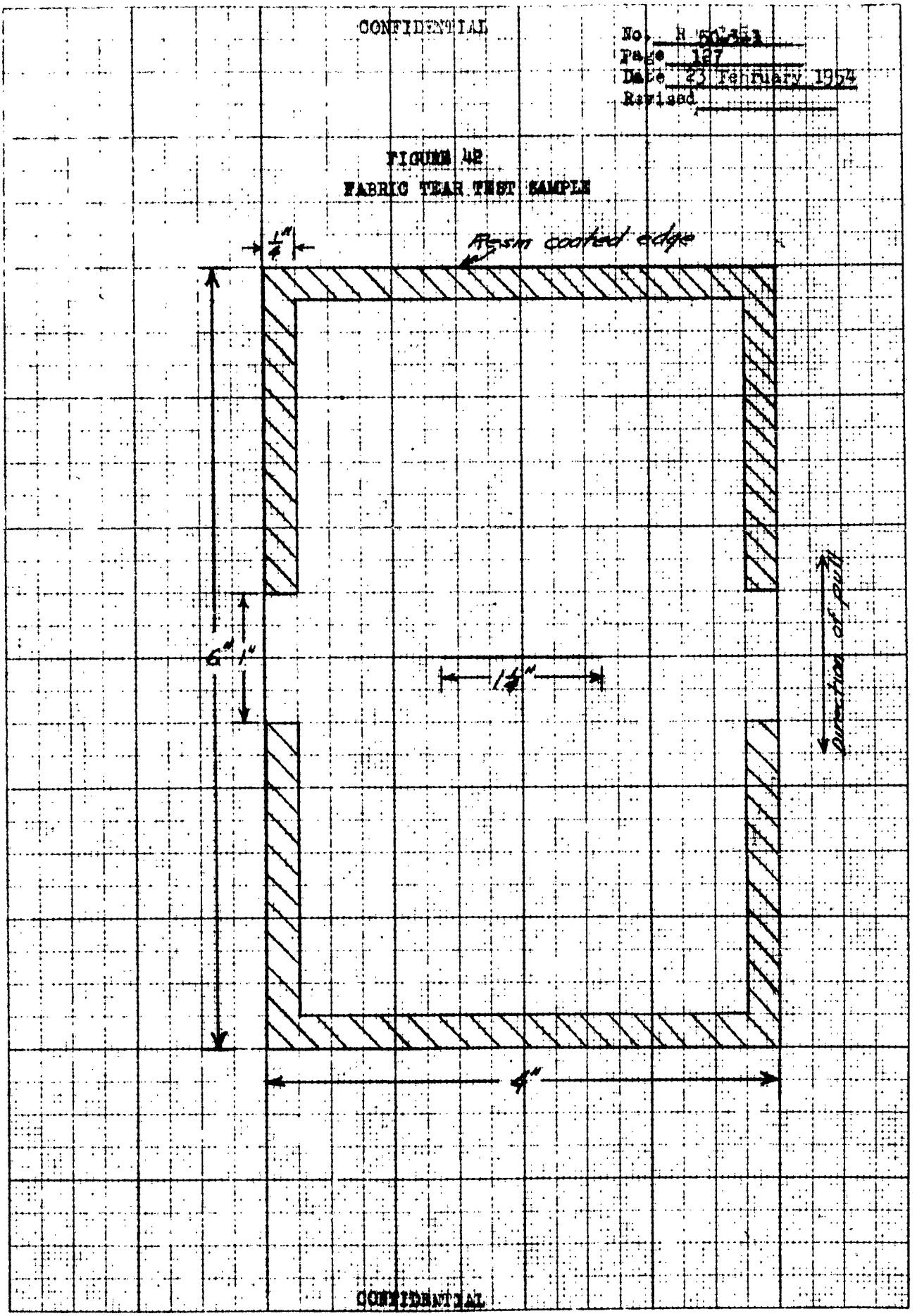

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TABLE XVIII. TEAR STRENGTH OF TEST FABRICS

Fabric No.	Tear Strength, Lbs		Tear Strength Weight Ratio
	Tongue	Cut	
2417	---	82.2	316
2583/S	---	59.2	285
2673/9	11.6	60.2	274
2680	5.0	28.8	142
2793	31.2	106.1	413
2887	6.7	44.8	281
2907	19.8	73.0	270
2941	---	53.3	385
2950	---	97.9	408
10,029	5.1	30.2	106
10,030	8.3	46.6	180
10,031	17.5	66.0	255
10,031/1	25.2	86.4	312
10,068	---	50.8	282
15,000	30.7	89.9	339
15,008	12.5	51.4	234
7162	4.7	21.5	117
20,075	---	47.0	164
20,085	---	35.6	150
5013	---	52.6	164

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5.3.1.6 Static Load Tests

As part of the screening operation on fabrics, static load tests were carried out to determine creep and also time to break. One inch by six inch ravelled strip samples, have two lines across the width and 76mm apart, were clamped in maple blocks. The upper block was fastened to a metal frame. To the lower block was attached a bag loaded with a weighed amount of lead shot corresponding to a definite percentage of the Scott tester breaking load of a ravelled strip sample. The load was applied immediately after the sample was carrying the full load. The distance was measured again at intervals to determine creep. The time to break also was noted. Temperature and humidity were not controlled. They were the same for all the samples in one series.

Since these tests were conducted over a period of twelve months, the creep progress of the samples will be shown for each quarter (i.e. 3 month periods).

5.3.1.6.1 First quarter

The creep curves of all the samples are given in Figures 43 to 51. The data are summarized in Table XIX.

Nylon and Orlon fabrics exhibit definite creep under load. Dacron, Fortisan, and cotton fabrics have practically flat creep curves. This lack of creep makes Dacron more desirable than nylon for use in an airship envelope fabric.

The change in initial elongation with load is much less for Fortisan and for cotton so their creep curves under different loads are close together. This is to be expected from the shape of

the load-elongation curves where changes in load cause little change in elongation.

There seems to be no correlation between the ability to withstand a static load on any other property of the fabric so far determined.

The Dacron fabrics withstand loads for the longest times--another desirable property of Dacron. Fortisan, cotton, and Orlon fabrics fail in shorter times. Nylon fabrics are variable in failure time with no correlation between this time and fabric construction or properties.

This failure under load may be due partly to sensitivity to stress concentration at the clamps or to unequal distribution of load upon the individual yarns. While no quantitative comparison can be made, it is believed that the qualitative differences observed are significant. As a practical matter, sensitivity to stress concentration is a point of weakness against a fabric and the use of a less sensitive material should be favored.

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FIGURE 43

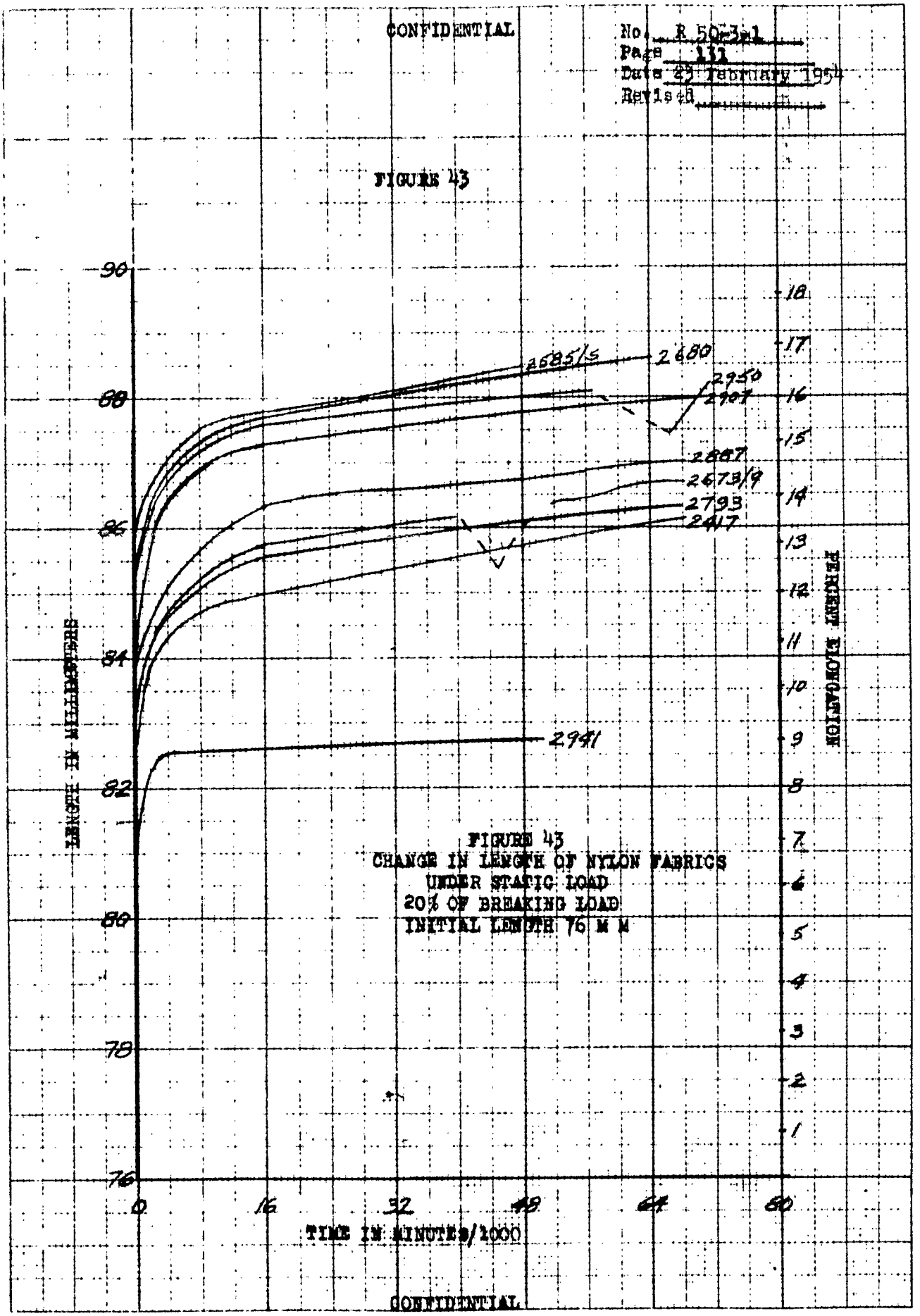

FIGURE 43
CHANGE IN LENGTH OF NYLON FABRICS
UNDER STATIC LOAD
20% OF BREAKING LOAD
INITIAL LENGTH 76 M M

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FIGURE 44
CHANGE IN LENGTH OF NYLON FABRICS
UNDER STATIC LOAD
40% OF BREAKING LOAD
INITIAL LENGTH 76 M M

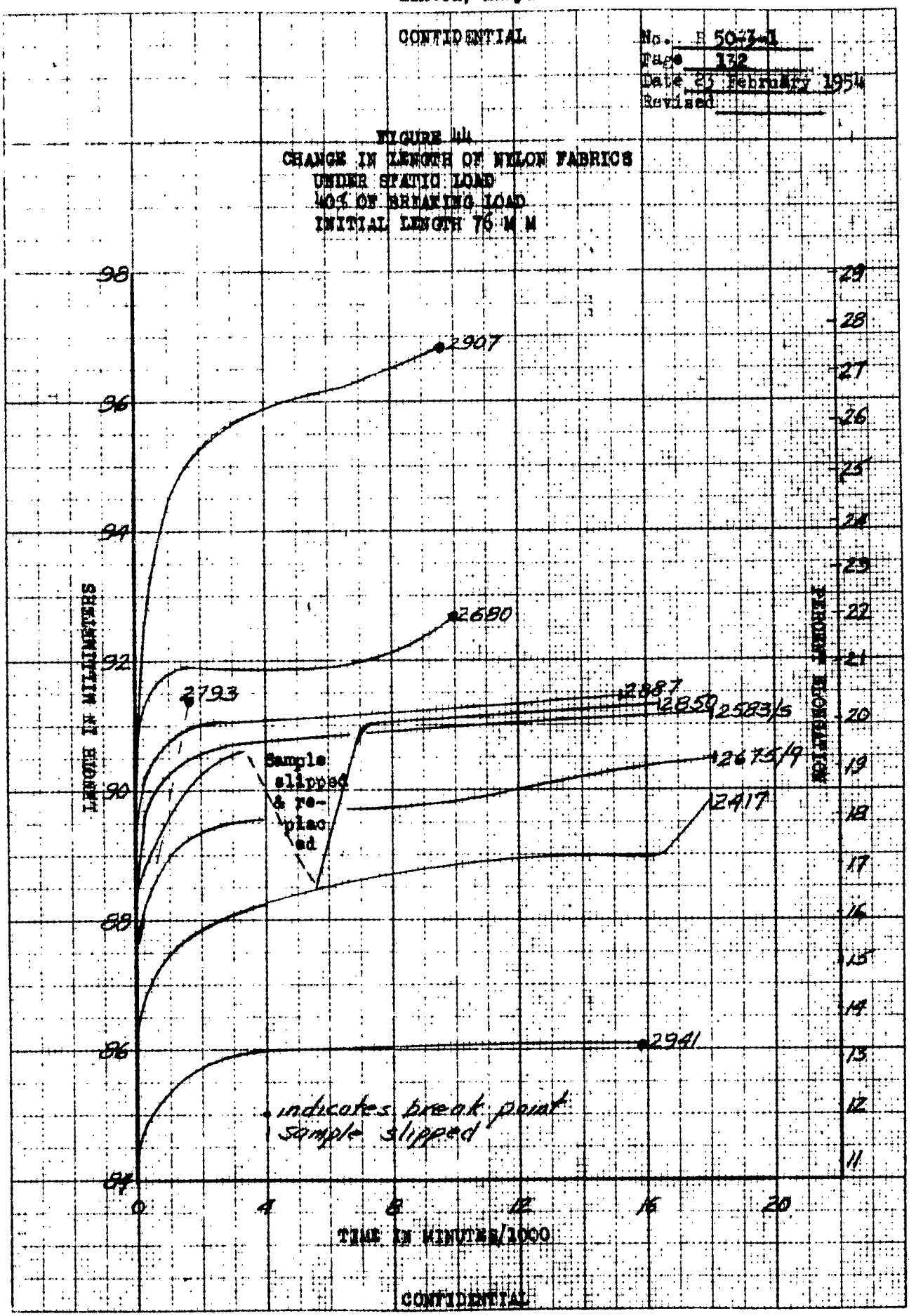

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FIGURE 45
CHANGE IN LENGTH OF NYLON FABRICS
UNDER STATIC LOAD
60% OF BREAKING LOAD

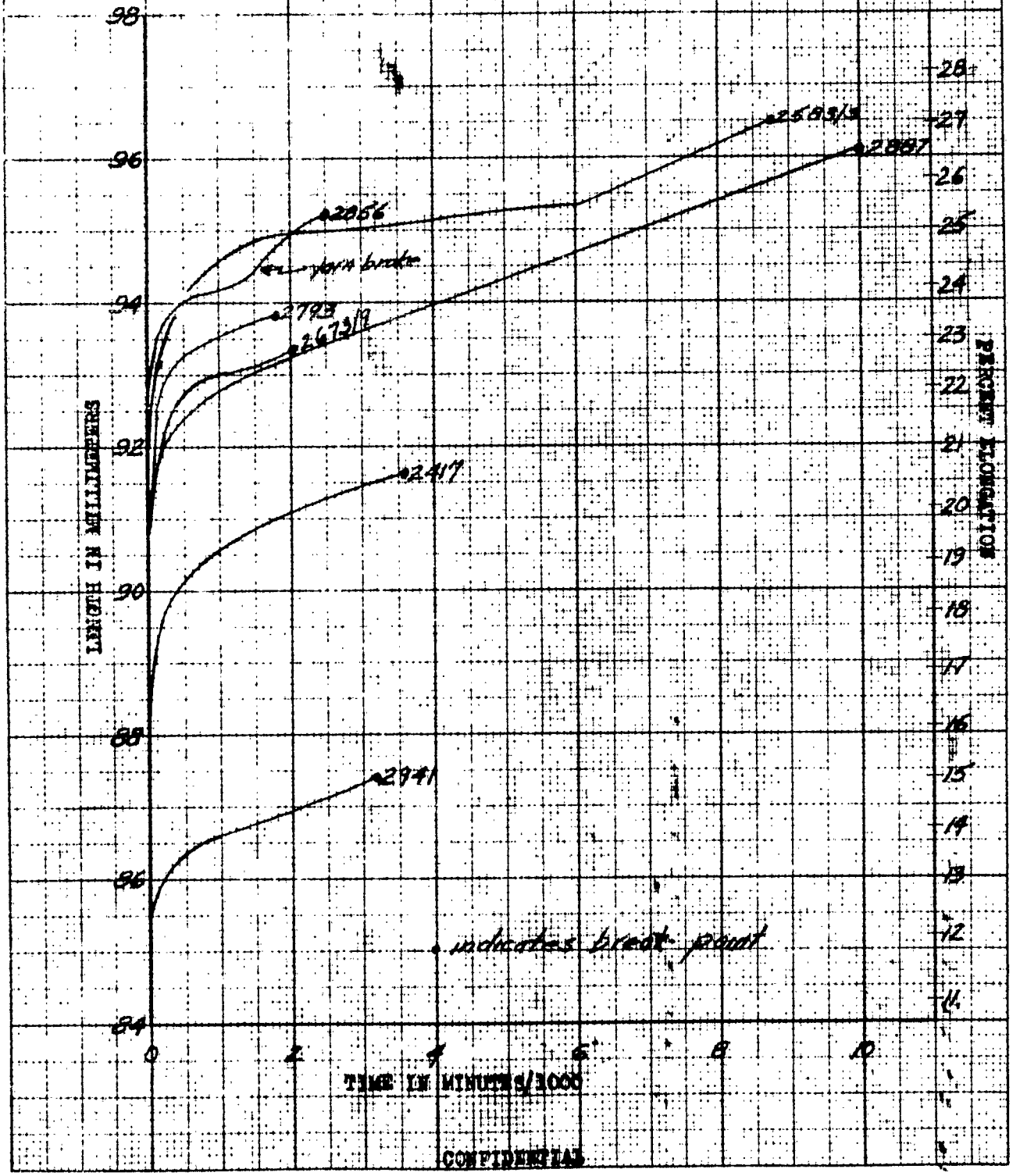

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FIGURE 46

CHANGE IN LENGTH OF ORLON FABRIC
UNDER STATIC LOAD
20% OF BREAKING LOAD
INITIAL LENGTH 76 M M

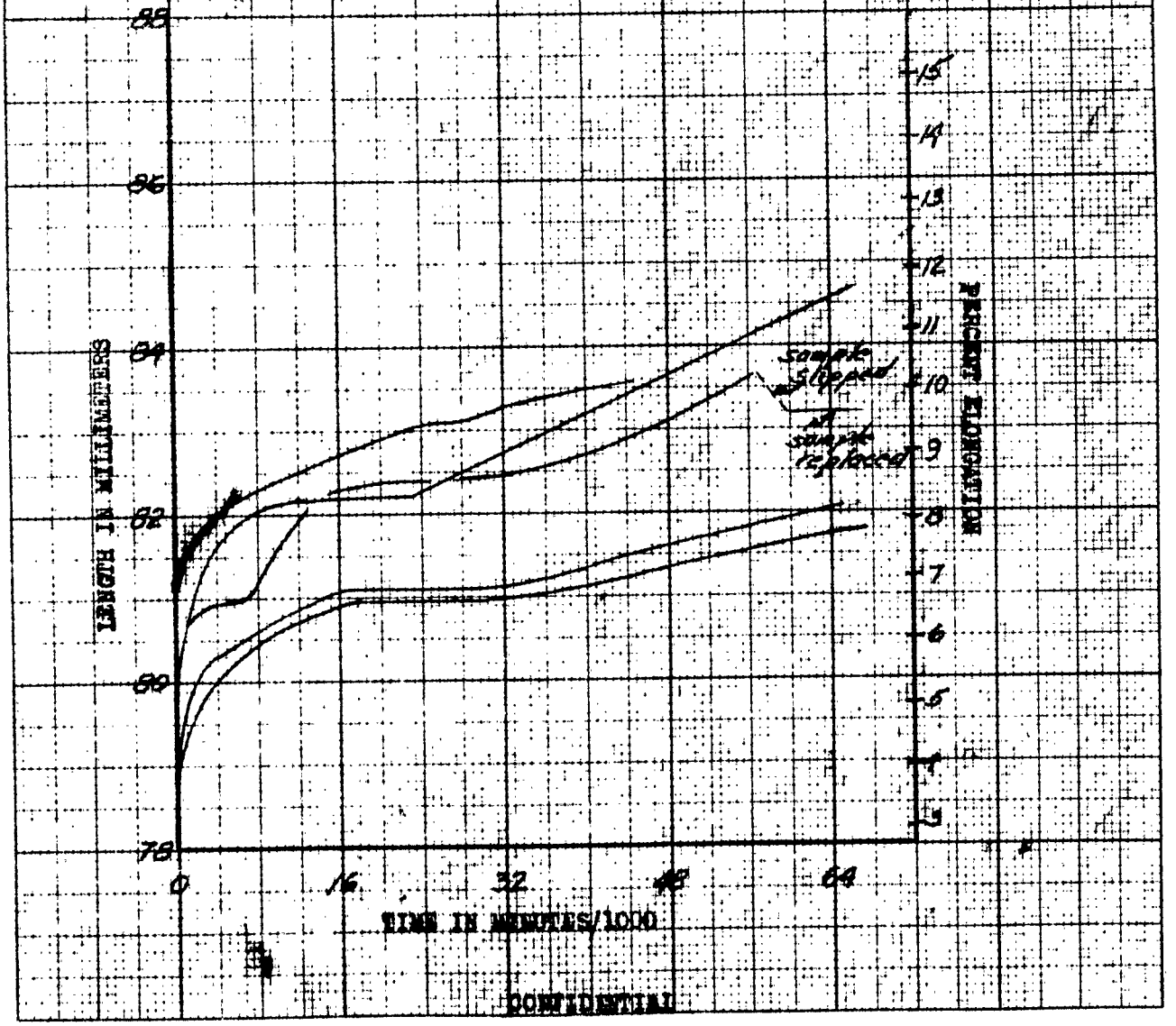

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FIGURE 47
CHANGE IN LENGTH OF ORLON FABRICS
UNDER STATIC LOAD
40% AND 60% OF BREAKING LOAD - INITIAL LENGTH 76 M M

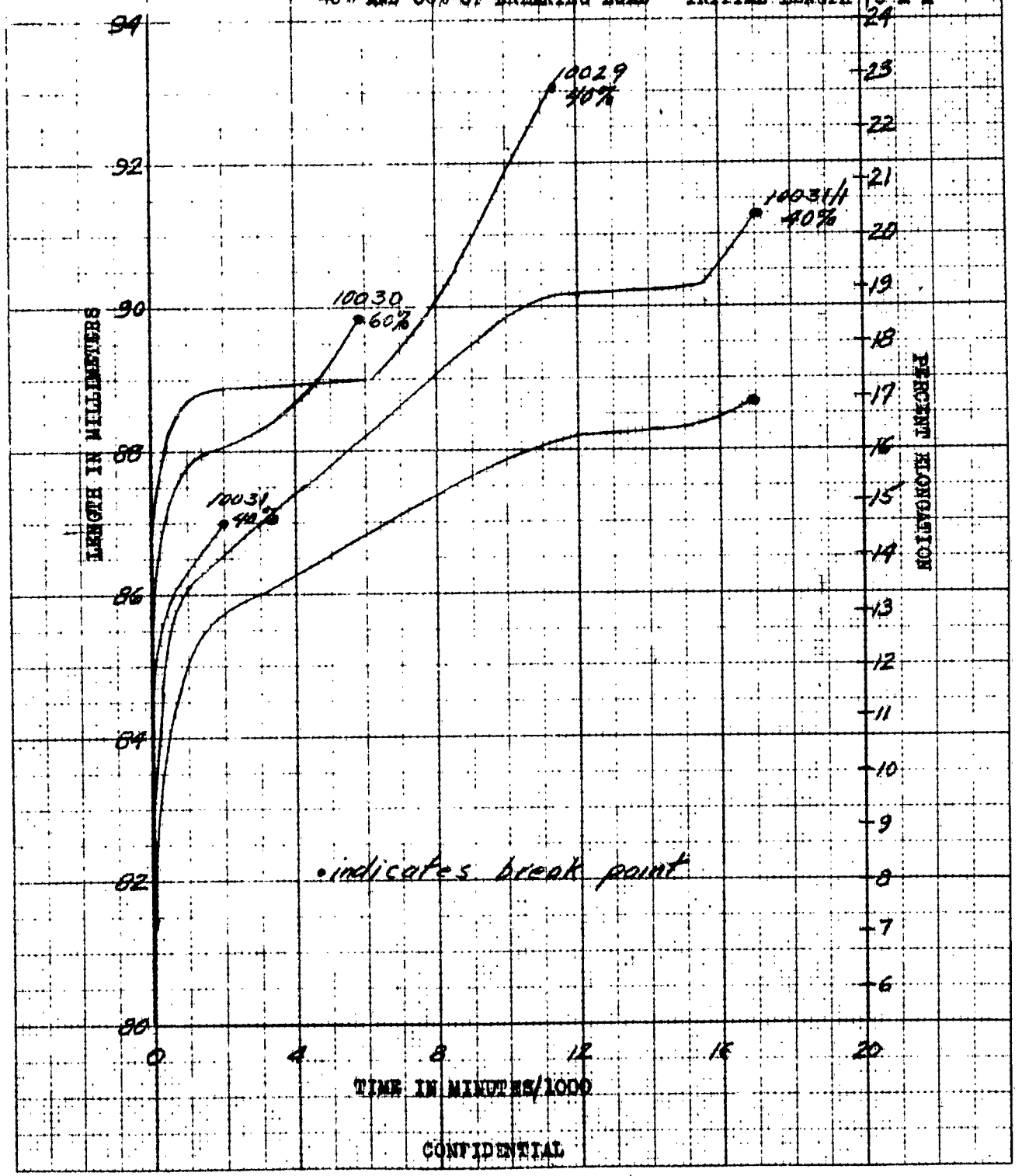

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FIGURE 48
CHANGE IN LENGTH OF DACRON
FABRICS UNDER STATIC LOAD
20% OF BREAKING LOAD
INITIAL LENGTH 76 M M

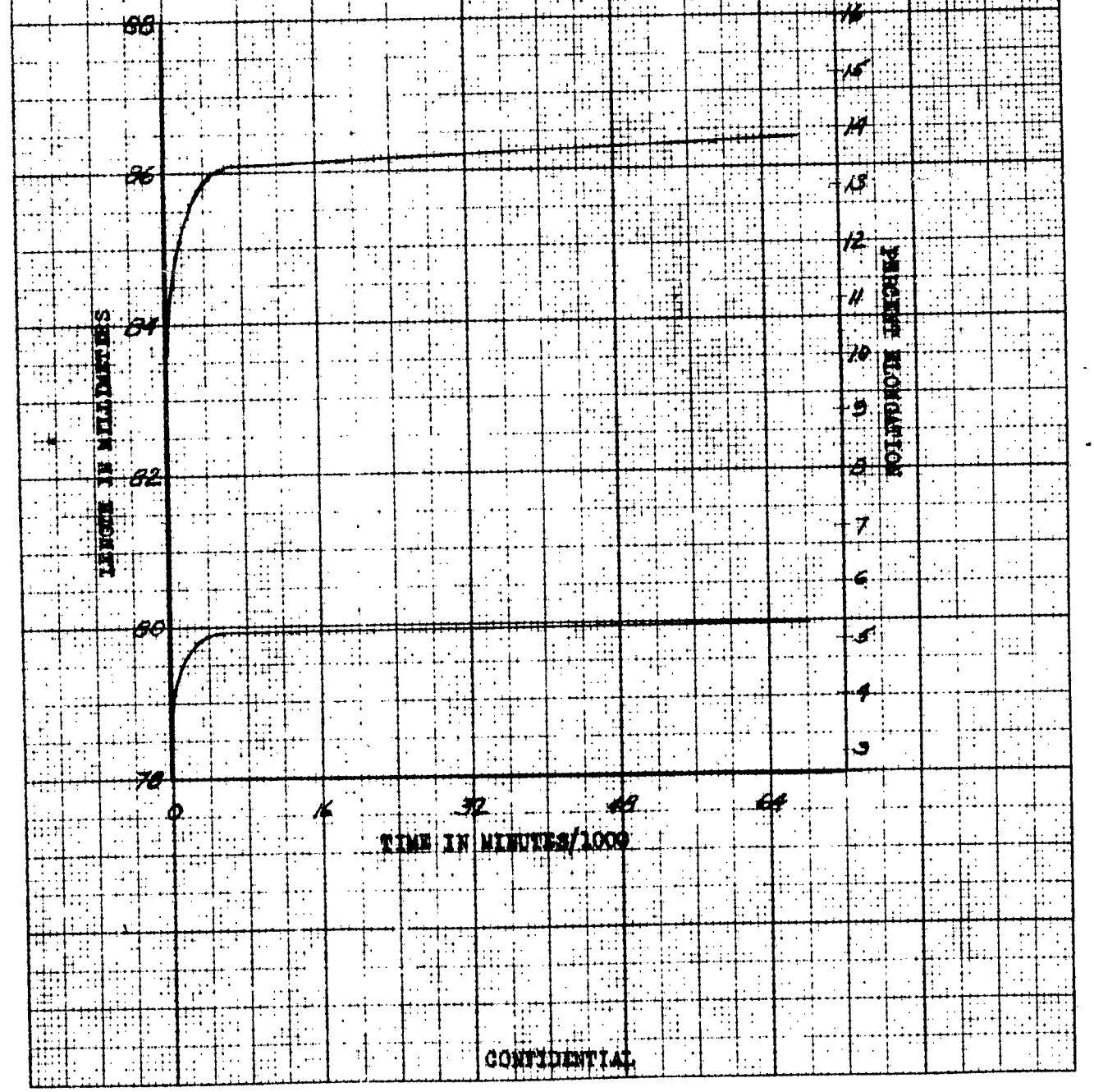

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FIGURE 49
CHANGE IN LENGTH OF DACRON FABRICS
UNDER STATIC LOAD
40% and 60% OF BREAKING LOAD
INITIAL LENGTH 76 M M

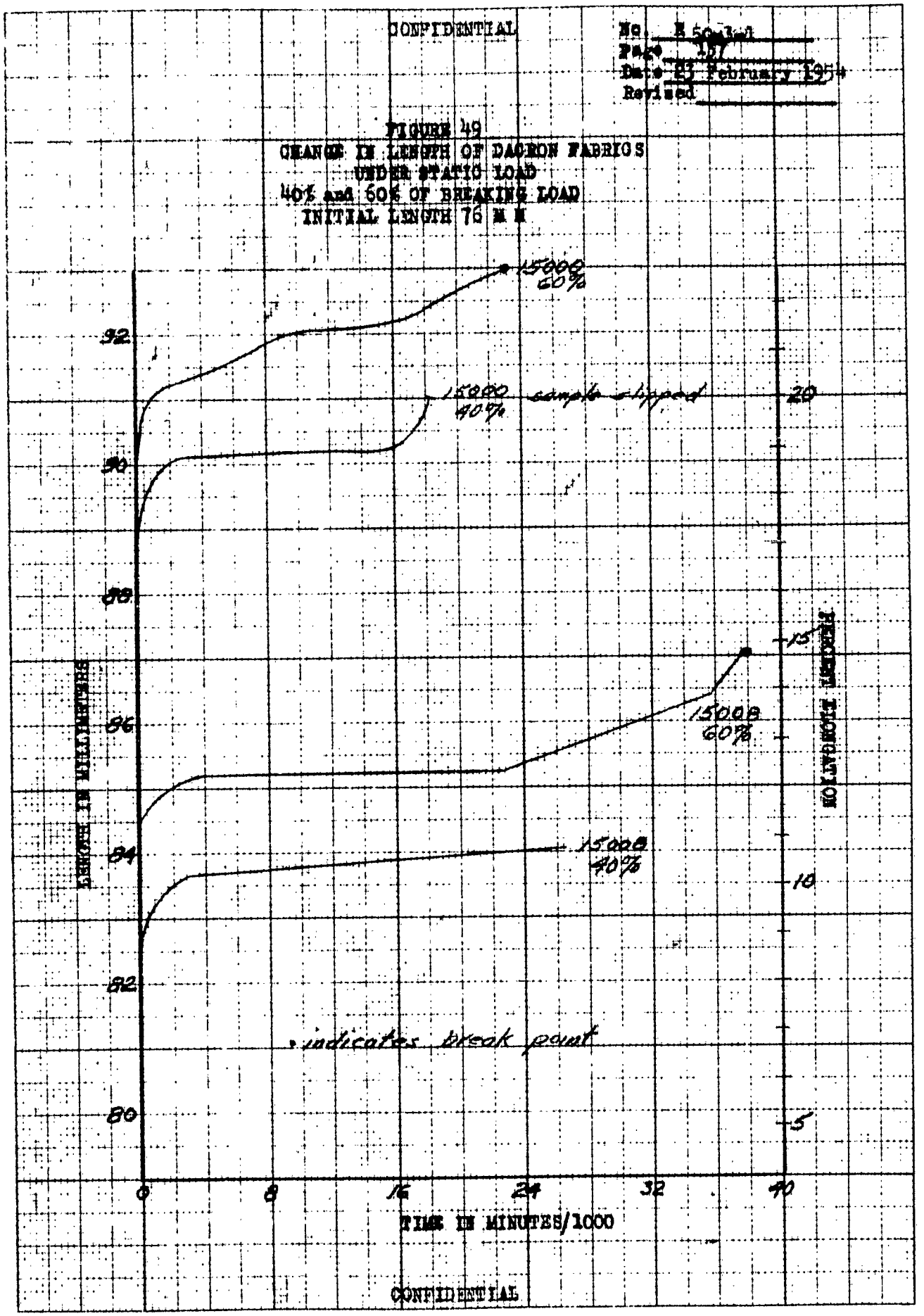

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FIGURE 50
CHANGE IN LENGTH OF FORTISAN FABRICS
UNDER STATIC LOAD
20%, 40% AND 60% OF BREAKING LOAD
INITIAL LENGTH 76 M M

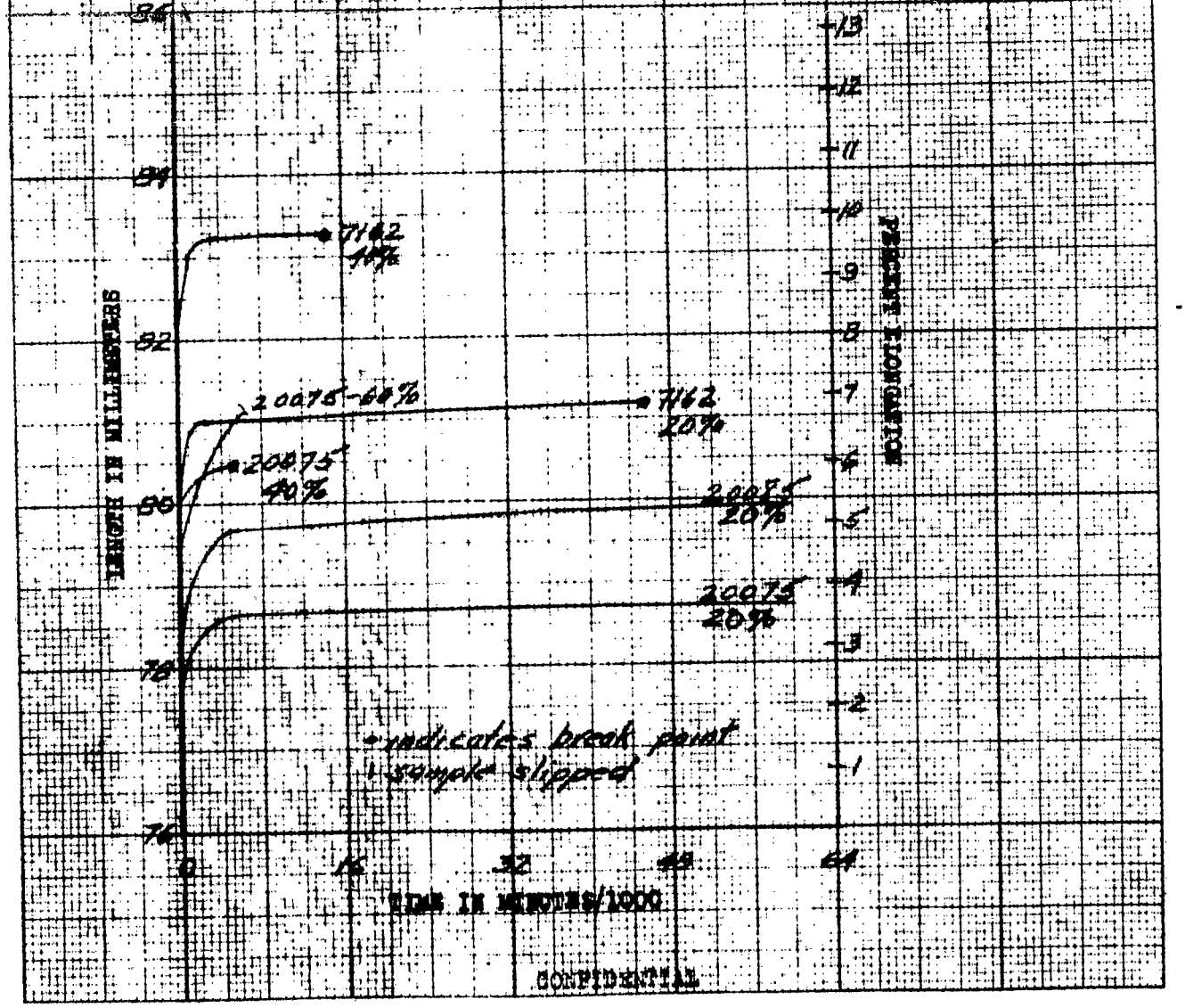

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FIGURE 51
CHANGE IN LENGTH OF COTTON FABRIC
UNDER STATIC LOAD
20%, 40%, AND 60% OF BREAKING LOAD
INITIAL LENGTH 76 M M

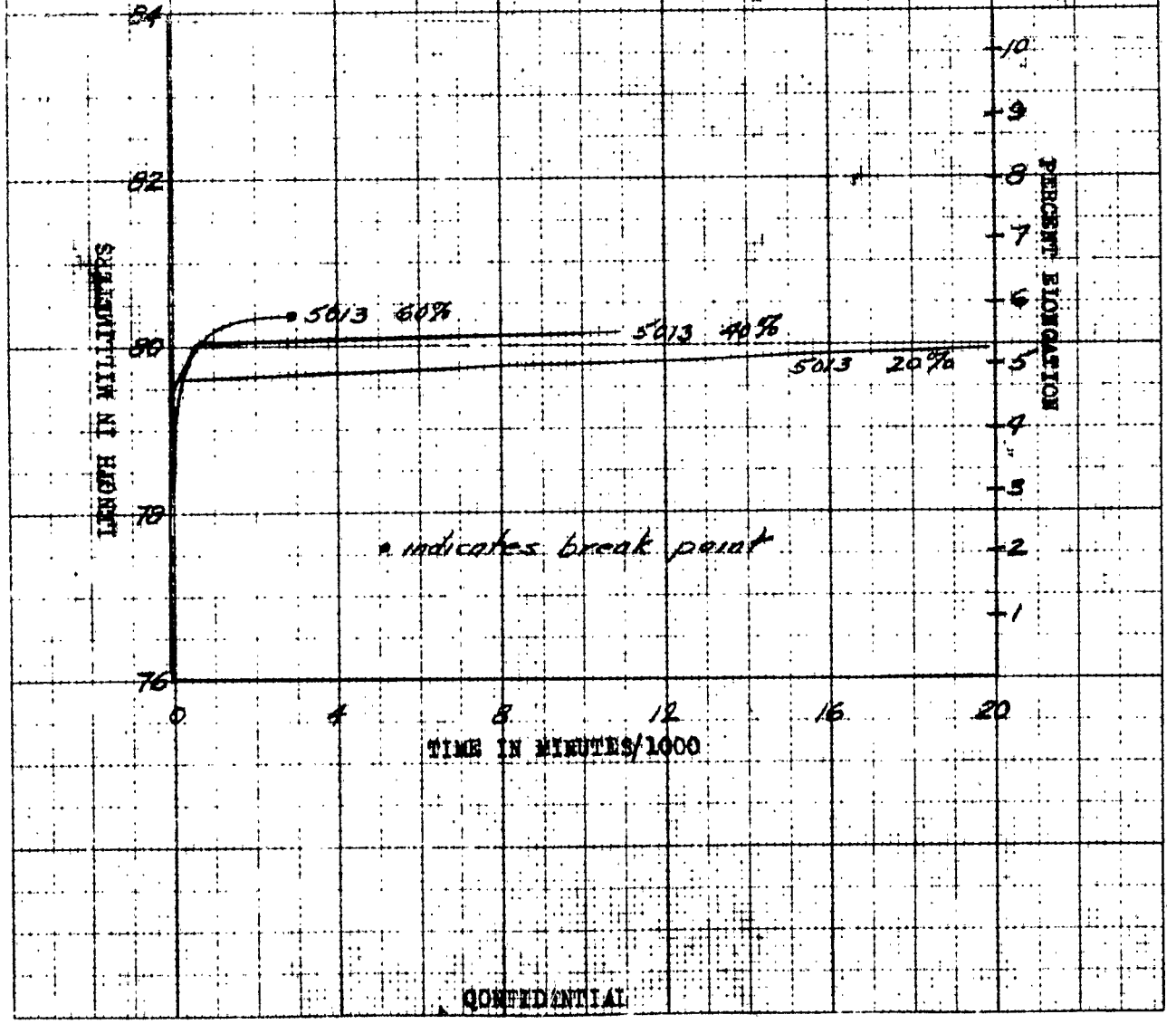

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TABLE XIX. SUMMARY OF STATIC LOAD TESTS ON FABRICS

Fabric No.	INITIAL ELONGATION			ELONGATION TO BREAK			TIME TO BREAK HRS.		
	20" Load	40" Load	60" Load	20" Load	40 Load	60" Load	20" Load	40" Load	60" Load
2417	9.2	13.0	15.2	---	---	20.5	---	---	60
2583/S	10.3	15.3	21.8	---	---	26.9	---	---	148
2673/9	9.2	15.6	19.6	---	---	23.0	---	---	35
2680	12.5	19.0	23.0	---	20.1	?	---	173	0.07
2793	8.5	15.3	19.8	---	20.5	23.4	---	30	28
2887	10.7	17.2	20.4	---	---	26.4	---	---	172
2907	10.6	18.5	23.1	---	27.4	25.6	---	220	1.2
2941	6.7	11.3	14.5	---	13.3	15.0	---	270	53
2950	15.5	15.3	21.3	---	---	25.2	---	---	40
10,029	4.6	11.2	16.0	---	22.7	?	---	197	0.05
10,030	3.0	7.9	11.0	---	15.9	18.4	---	300	108
10,031	2.7	9.3	12.2	---	15.8	?	---	48	0.3
10,031/1	3.3	9.3	11.9	---	20.3	?	---	284	2.5
10,068	4.0	12.2	13.3	---	?	?	---	<17	0.05
15,000	10.2	17.1	18.6	---	---	22.7	---	---	383
15,008	4.0	8.2	11.3	---	---	14.8	---	---	630
7162	5.2	8.2	9.2	6.9	9.7	?	1106	220	0.5
20,075	2.4	5.3	4.7	---	6.0	6.0	---	69	20
20.085	3.2	4.3	6.3	---	5.4	7.0	---	220	20
5013	4.9	3.6	4.8	---	5.3	5.5	---	175	58

A dash (-) indicates that the sample has not broken, a question mark (?) indicates that no reading was obtained before the sample broke so elongation is unknown.

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5.3.1.C.2 Second quarter

All curves of the nylon fabrics at 20% load show that creep is continuing at a rate which seems to be constant (Figure 52). The slope of the curve for nylon fabric 2041 now seems to be about the same as the slopes of the other curves. Previously, the curve was flatter. The main difference between the fabrics appears to be in the percent of initial elongation under load and in the time necessary for the rate of creep to become constant.

In the first tests at 40% load, a number of nylon samples slipped while some broke. The samples which slipped were repeated. At this load, the rate of creep appears to become constant after a shorter time than for the 20% loads. Some samples, however, break before the slope of the curves becomes constant. The curves are shown in Figure 53.

No 60% load tests were repeated. Examination of the curves in the first quarter shows that all the slopes are about the same, and that the rate of creep becomes constant in a relatively short time.

The rate of creep of some of the Orlon fabrics under 20% load seems to have become constant, while others still show erratic behavior as shown in Figure 54. The slopes which seem to be constant are the same as the slopes of nylon fabrics at 20% load. The nylon fabrics have higher initial and final elongation.

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No tests of Orlon fabrics under 40% and 60% loads were repeated.

Dacron fabric 15003 shows no creep after a few days under 20% load. This curve is practically identical with that of RR cotton under 20% load. The 40% load curve also shows no creep after a short time. In contrast to RR cotton, elongation is quite a bit more under 40% load than under 20% load.

Dacron fabric 15000 still is undergoing some creep at a decreasing rate under 20% load and at a lower rate under 40% load. The elongations are higher than for fabric 15008.

Creep curves of Dacron fabrics are shown in Figure 55.

Fortisan fabric 7162 still exhibits creep at a constant rate under 20% load. Creep of fabric 20075 seems to have stopped. Fabric 20085 showed no creep after a few days under load. This curve is practically identical to the curves of RR cotton and Dacron 15008.

Creep curves of Fortisan fabrics are shown in Figure 56.

All three cotton fabrics used in the standard airship envelope have been obtained. Their creep curves are shown in Figure 57 for 20% loads and in Figure 58 for 40% loads and 60% loads. All the samples under 20% load have stopped creeping. They vary in the extent of elongation.

The RR basket weave fabric shows little change in elongation with load. The BB cloth shows the most change.

The time to break under 40% and 60% loads is quite short except for the BB cloth under 40% load.

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Table XX summarizes the results of static load tests. A number of tests were repeated, either because the sample slipped, or to try to obtain more accurate data especially for the standard cotton sample. The checks on this fabric are only fairly good.

The static load tests will be continued. No more samples will be repeated except for standard fabrics. The tests have served their purpose of disclosing differences in the behavior of various fabrics, although the results are not quantitative. They show that cotton, Fortisan and Dacron are most likely to give overlap fabrics which will be dimensionally stable under operating loads.

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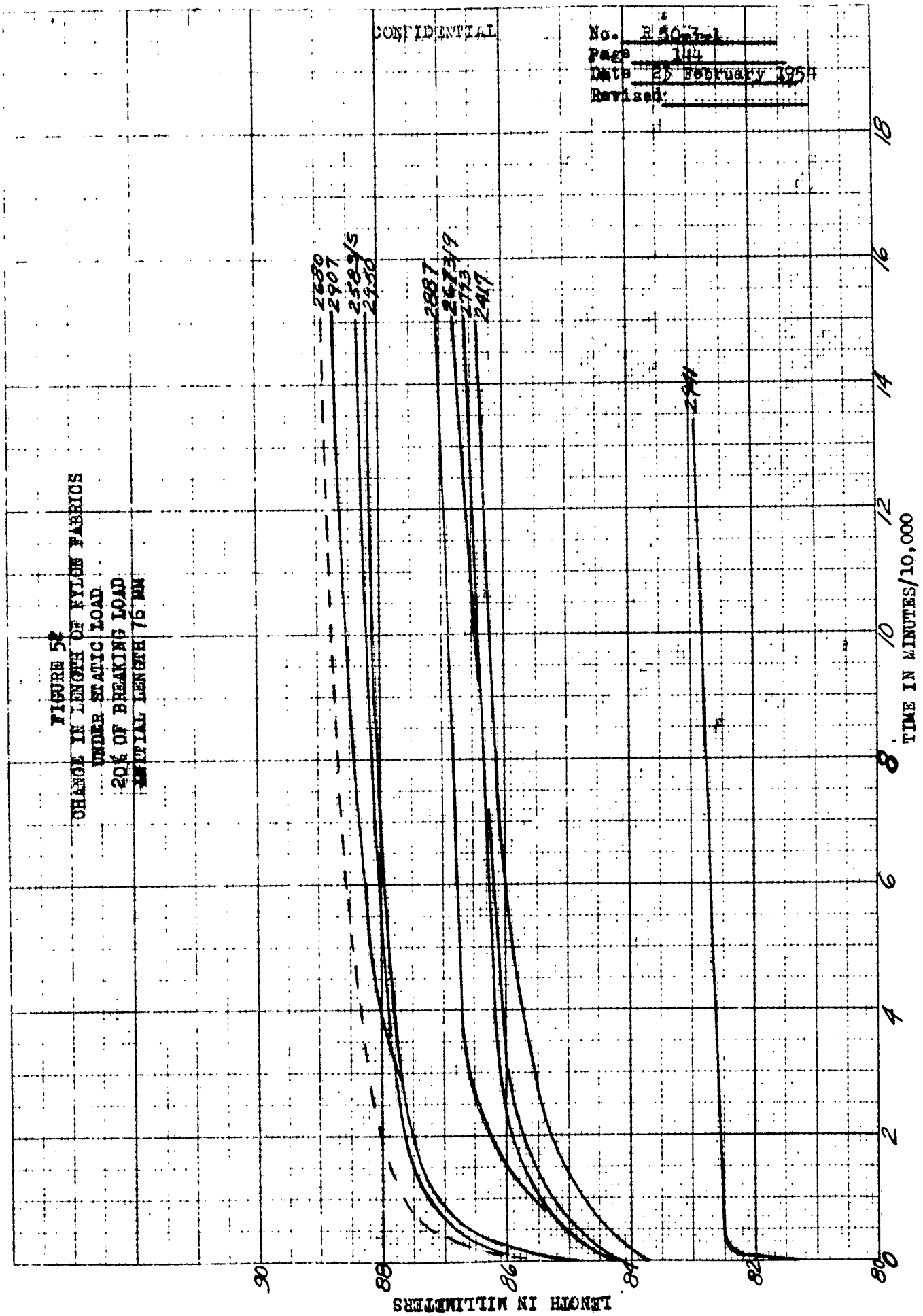

FIGURE 52
CHANGE IN LENGTH OF NYLON FABRICS
UNDER STATIC LOAD
20% OF BREAKING LOAD
INITIAL LENGTH 76 MM

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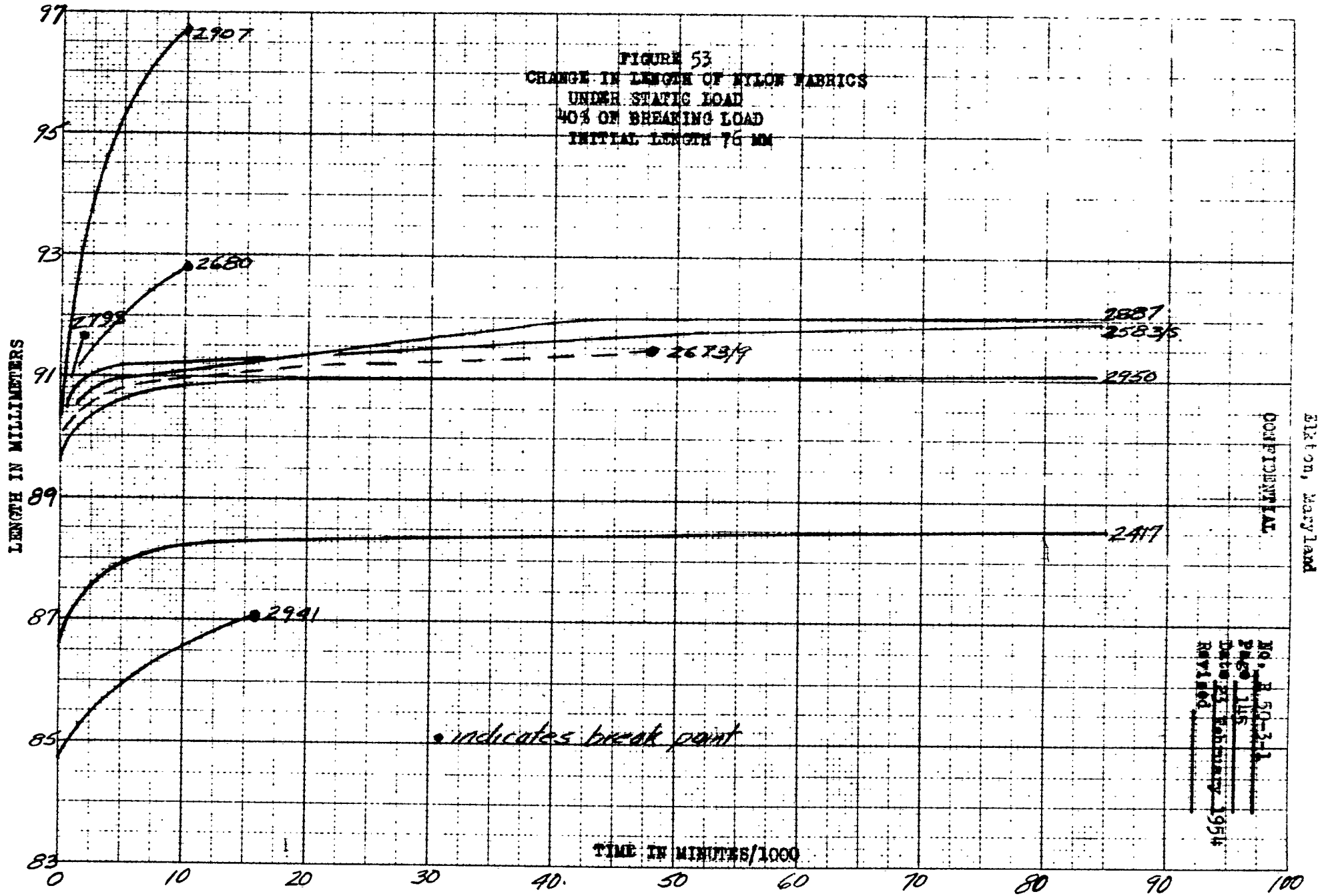

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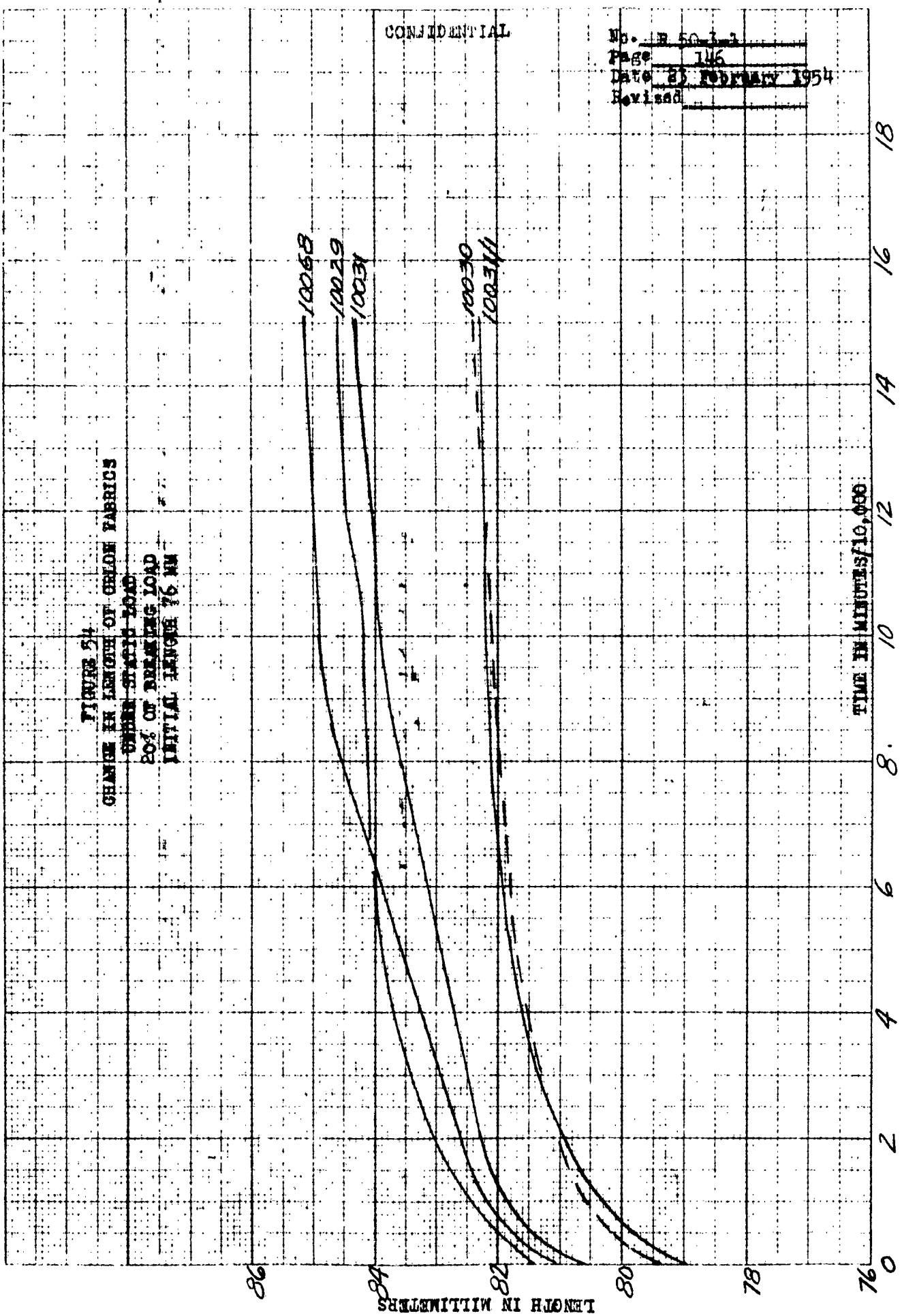

FIGURE 54
CHANGE IN LENGTH OF ORLON FABRICS
UNDER STATIC LOAD
20% OF BREAKING LOAD
INITIAL LENGTH 76 MM

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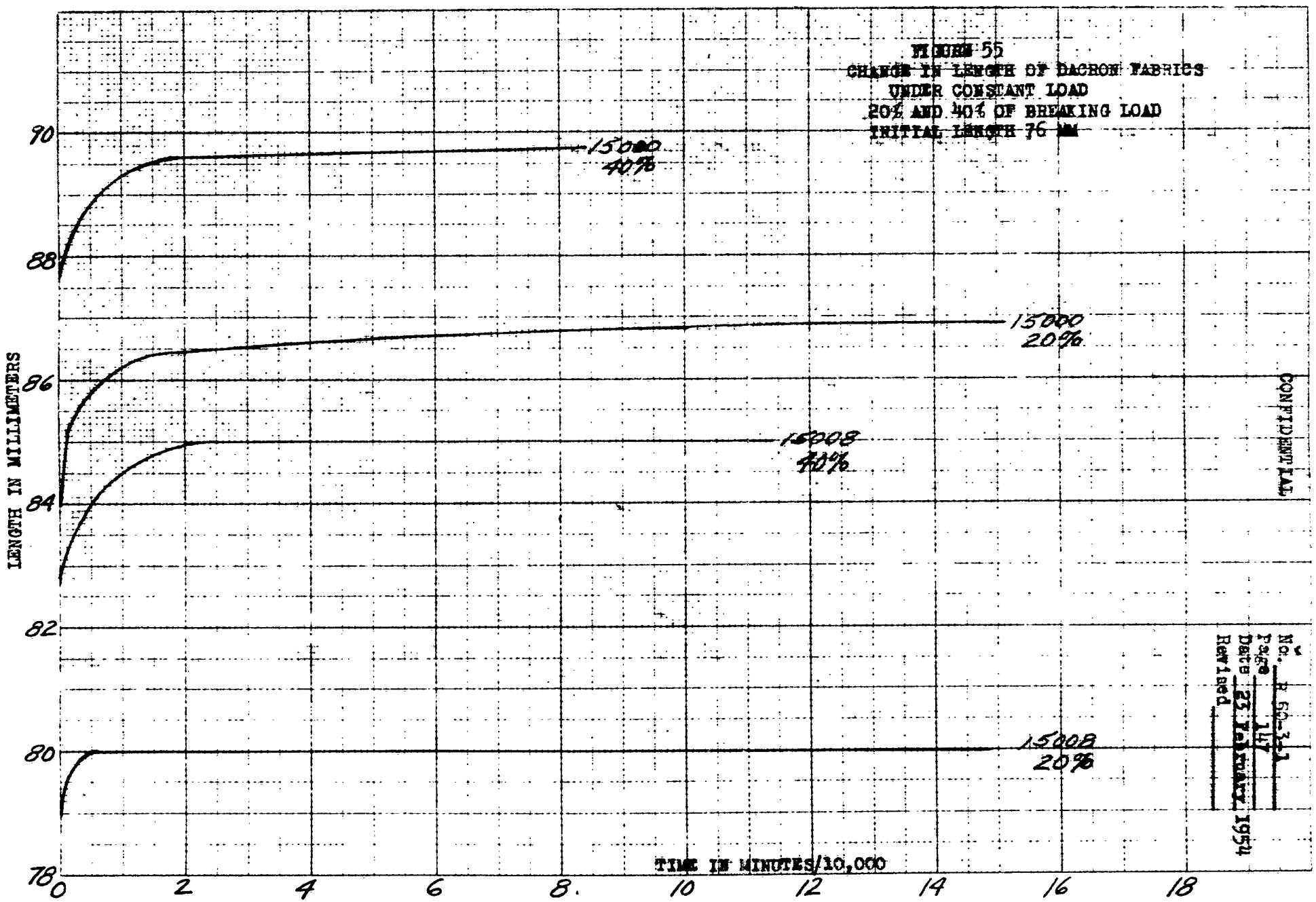

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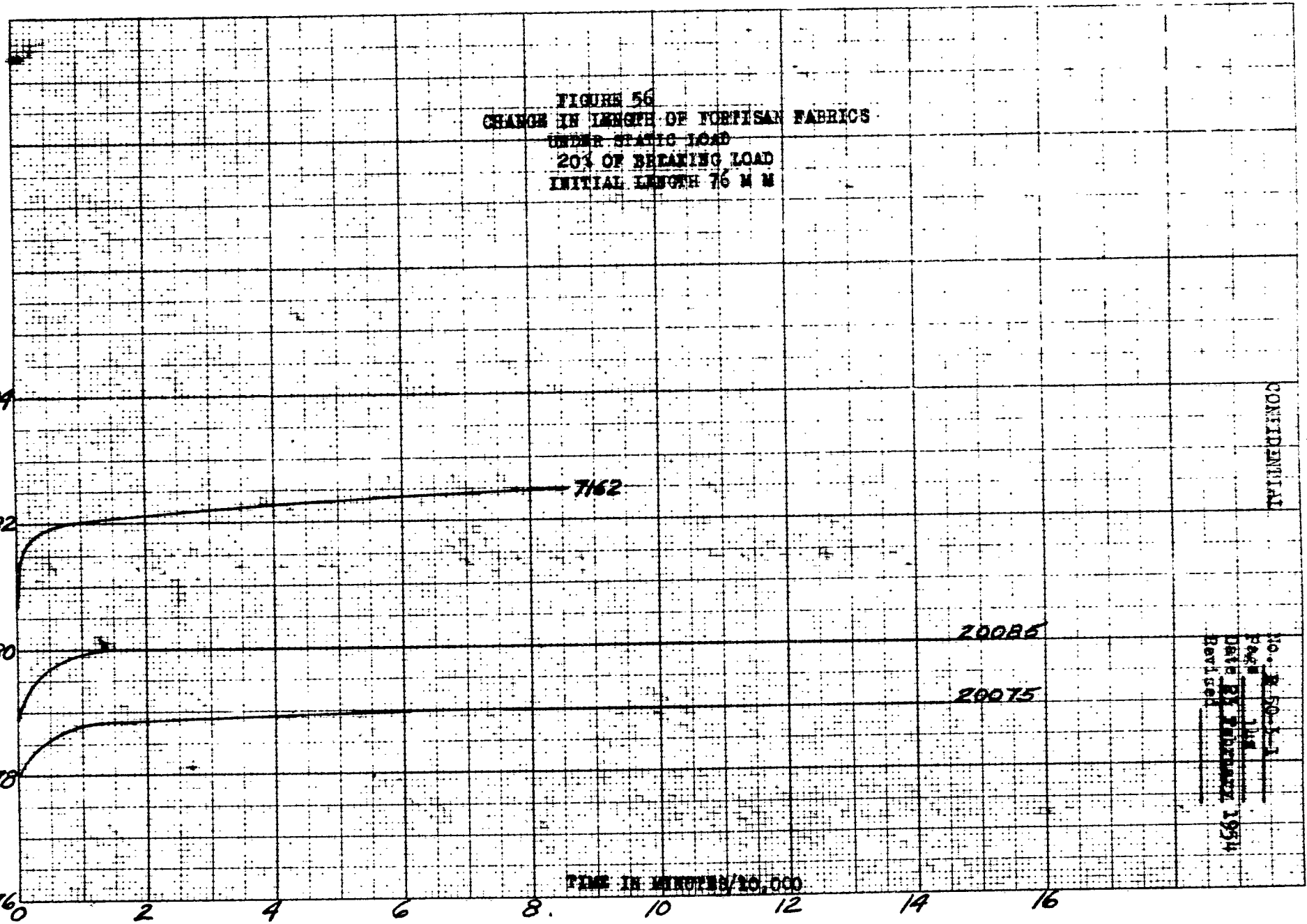

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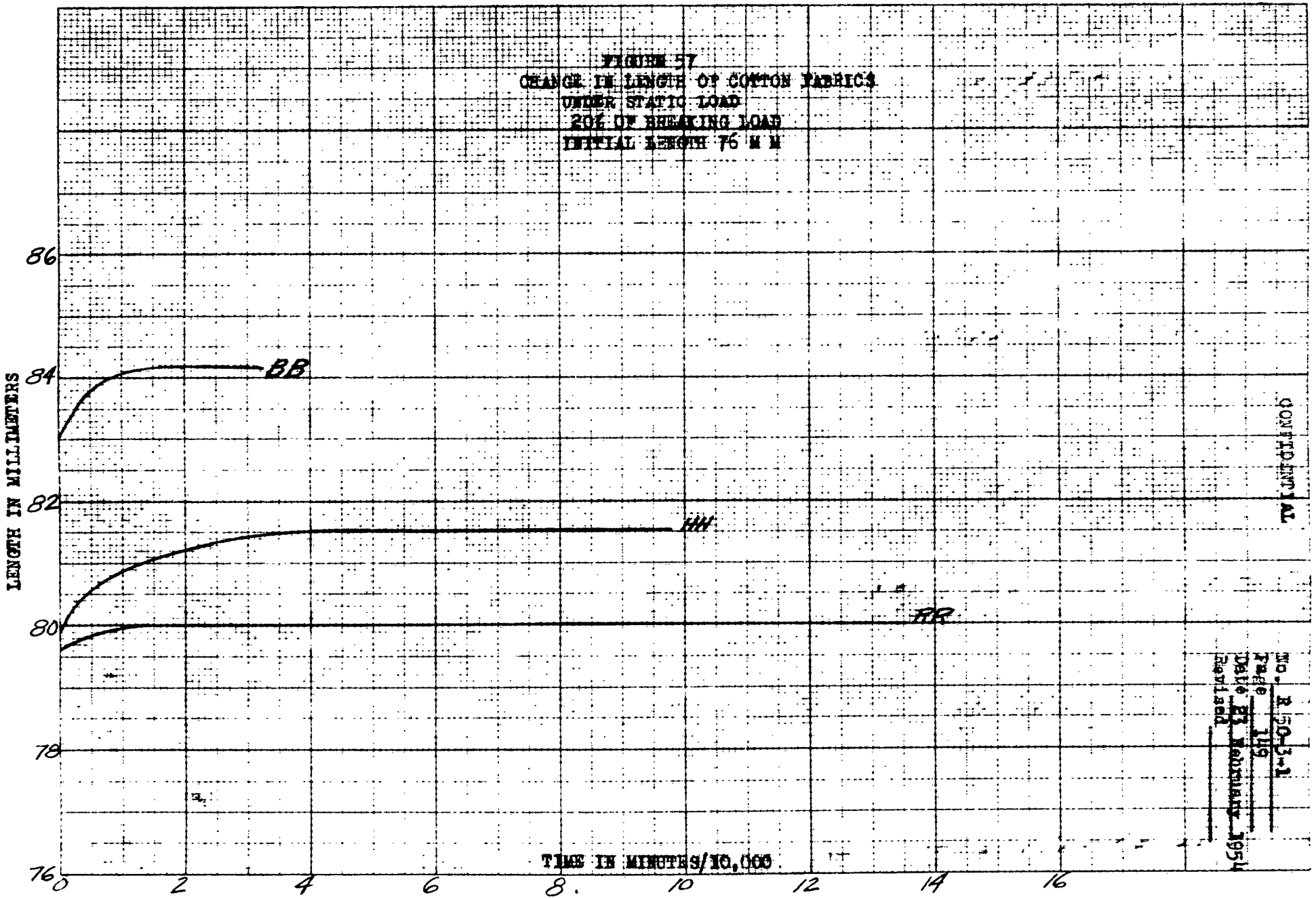
FIGURE 57
CHANGE IN LENGTH OF COTTON FABRICS
UNDER STATIC LOAD
20% OF BREAKING LOAD
INITIAL LENGTH 76 M M



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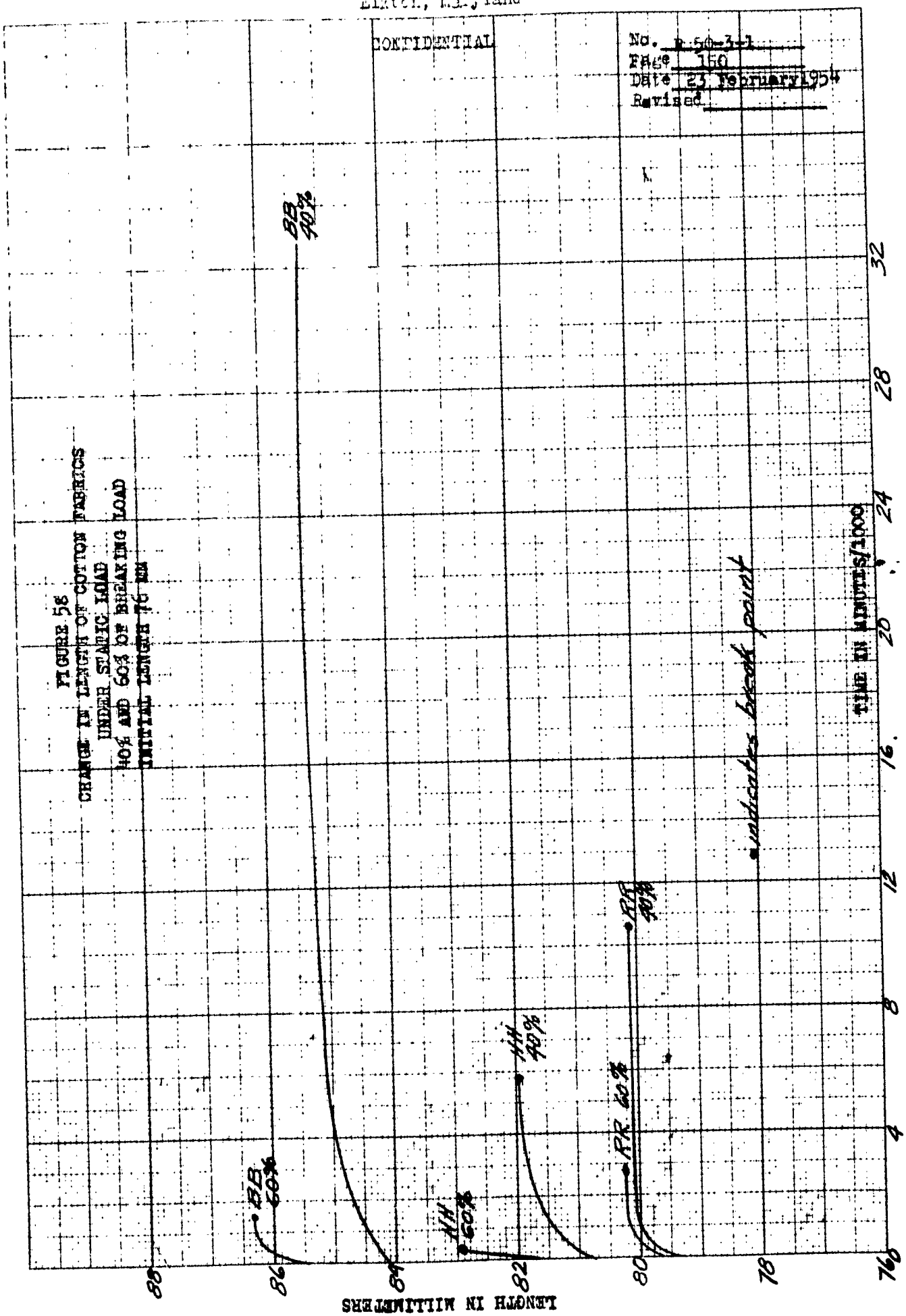

FIGURE 58
CHANGE IN LENGTH OF COTTON FABRICS
UNDER STATIC LOAD
40% AND 60% OF BREAKING LOAD
INITIAL LENGTH 76 MM

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TABLE XX. SUMMARY OF STATIC LOAD TESTS ON FABRICS

Fabric No.	Initial Elongation--% 20% Load	40% Load	60% Load	Elongation at Break -% 20% Load	40% Load	60% Load	Time to Break, Hrs. 20% Load	40% Load	60% Load
2417	9.2	13.0 13.6	16.2	---	--- ---	20.5	---	slipped ---	60
2583/S	10.3	15.3 15.8		---	--- ---		---	slipped ---	
2673/9	9.2	15.6 17.1	19.3	---	--- 20.5	23.0	---	slipped 797	35
2680	12.5	19.0	23.0	---	20.1	?	---	173	0.07
2793	9.5	15.3	19.8	---	20.5	23.4	---	30	28
2887	10.7	17.2 16.8	20.4 17.2 19.7 20.8	---	--- ---	26.4 --- ---	---	slipped —	172 slipped slipped 193
2907	10.6	18.5	23.1	---	27.4	25.6	---	220	1.2
2941	6.7	11.3	12.5	---	13.3	15.0	---	270	53
2950	13.6	16.3 17.4	21.3	---	--- ---	25.2	---	slipped ---	40
10,029	4.6	11.2	16.0	---	22.7	?	---	197	0.05
10,030	3.0	7.9	11.0	---	15.9	18.4	---	300	108
10,031	2.7	9.3	12.2 14.5	---	15.8	? ?	---	48	0.3 0.02
10,031/1	3.3	9.3	11.9	---	20.3	?	---	284	2.5

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TABLE XX. SUMMARY OF STATIC LOAD TESTS ON FABRICS (continued)

Fabric No.	Initial Elongation -% 20% Load	40% Load	60% Load	Elongation at Break -% 20% Load	40% Load	60% Load	Time to Break, Hrs. 20% Load	40% Load	60% Load
10,068	4.0	12.2	13.3	---	?	?	---	>17	0.05
15,000	10.2	17.1 15.7	18.6	---	--- ---	22.7	---	slipped ---	383
15,008	4.0	8.2	11.3	---	---	14.8	---	---	630
7162	5.2 6.8	8.2	9.2 9.2	6.9 ---	9.7	? 10.0	1106 ---	220	0.5 1.5
20075	2.4	5.3	4.7 4.7	---	6.0 ---	6.0 ---	---	69	20 slipped 88
20085	3.2	4.3	6.3	---	5.4	7.0	---	220	20
5013(RR)	4.9 4.0	3.6 4.5	4.8 5.1 5.1 6.0 6.4	--- ---	5.3 6.5	5.5 ? ? ? 6.5	--- ---	175 200	58 0.15 0.2 0.67 2
HH	5.1	6.3	7.8 8.0 8.0 8.0 8.2 8.0	---	7.8	? 9.2 ? 8.3 ? 9.3	---	91	0 3.2 1 1.5 0 0.5
BB	9.2	10.6	12.5	---	---	13.5	---	---	26

A dash (-) indicates that the sample has not broken; a question mark (?) indicates that no reading of elongation was obtained before the sample broke.

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5.3.1.6.3 Third quarter

As static load tests were continued on the fabric samples, no changes in behavior were noted. The last conclusion about creep of nylon 2941 (greige) must be changed back to the original one that creep is much less than for scoured or heat-set fabrics. The latest results which define the curve more accurately show that creep has stopped. This is shown in Figure 90 where a comparison is made with coated fabrics. After ten days under load the creep curve is flat. This means that greige nylon fabrics may be suitable for use in envelopes.

These results are checked by those on the new fabrics, creep curves of which are shown in Figure 59. The mock leno and basket weave greige fabrics have flat creep curves, while their scoured and heat-set equivalents show definite creep. The nylon twill greige fabrics also show creep. These studies will be continued to prove this important point of lack of creep of greige nylon fabrics.

Creep tests on samples of heated (300°F., 30 minutes) fabrics are under way, but time has been too short to define the curves. They will be included in the next section (Fourth quarter).

The study of change in breaking strength with time under load was completed. Samples were loaded for 100,000 min. (approximately 70 days) and tensile strengths determined. The data is given in Table XXI and the curves are shown in Figure 60. These show that little or no change in strength takes place after 10 - 15 days under load. Elongation of all fabrics continues to decrease. This lowers the toughness index. Fortisan shows the greatest decrease in strength.

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FIGURE 59
CHANGE IN LENGTH OF FABRICS
UNDER STATIC LOAD
20% OF BREAKING LOAD

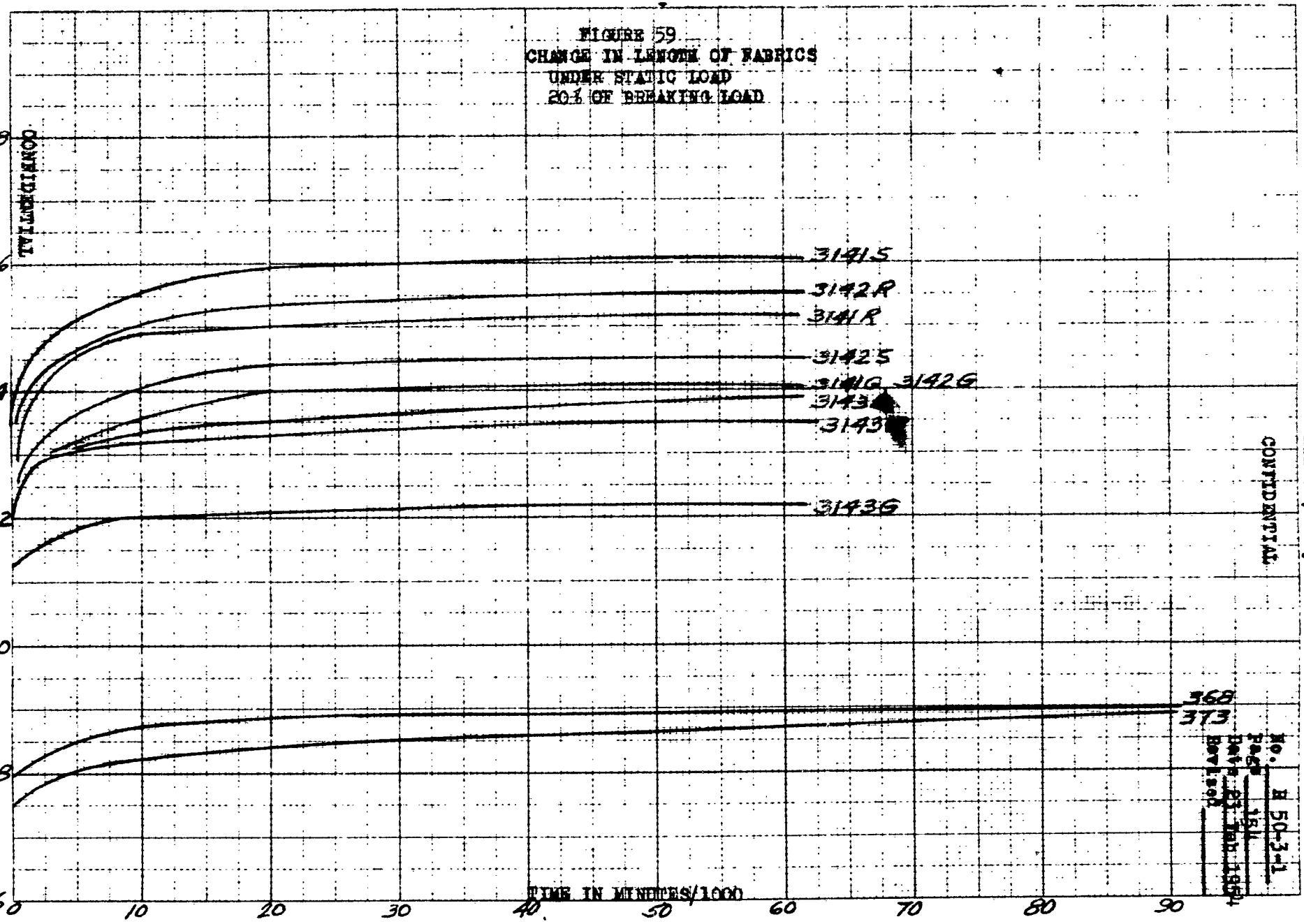

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TABLE XXI. CHANGE IN TENSILE STRENGTH WITH TIME UNDER STATIC LOAD (20% OF BREAKING LOAD)

Fabric	Time, Mins.	Tensile Strength Lbs/In.	Elongation %	Toughness Index
RR Cotton	0	136	4.6	3.1
	10,000	134	4.8	3.2
	50,000	137	3.7	2.5
	100,000	136	2.5	1.7
HH Cotton	0	41.5	7.3	1.6
	10,000	37	5.3	1.0
	50,000	33	4.0	0.7
	100,000	33	2.0	0.3
Fortisan 20075	0	245	8.3	10.3
	10,000	204	5.7	5.8
	50,000	208	3.8	3.9
	100,000	213	3.3	3.5
Nylon 2941	0	128	21.6	13.8
	10,000	122	16.0	9.8
	50,000	122	16.2	9.9
	100,000	118	14.0	8.3
Dacron 15000	0	184	27.0	24.8
	10,000	168	19.1	16.1
	50,000	188	16.7	15.7
	100,000	189	14.7	13.9

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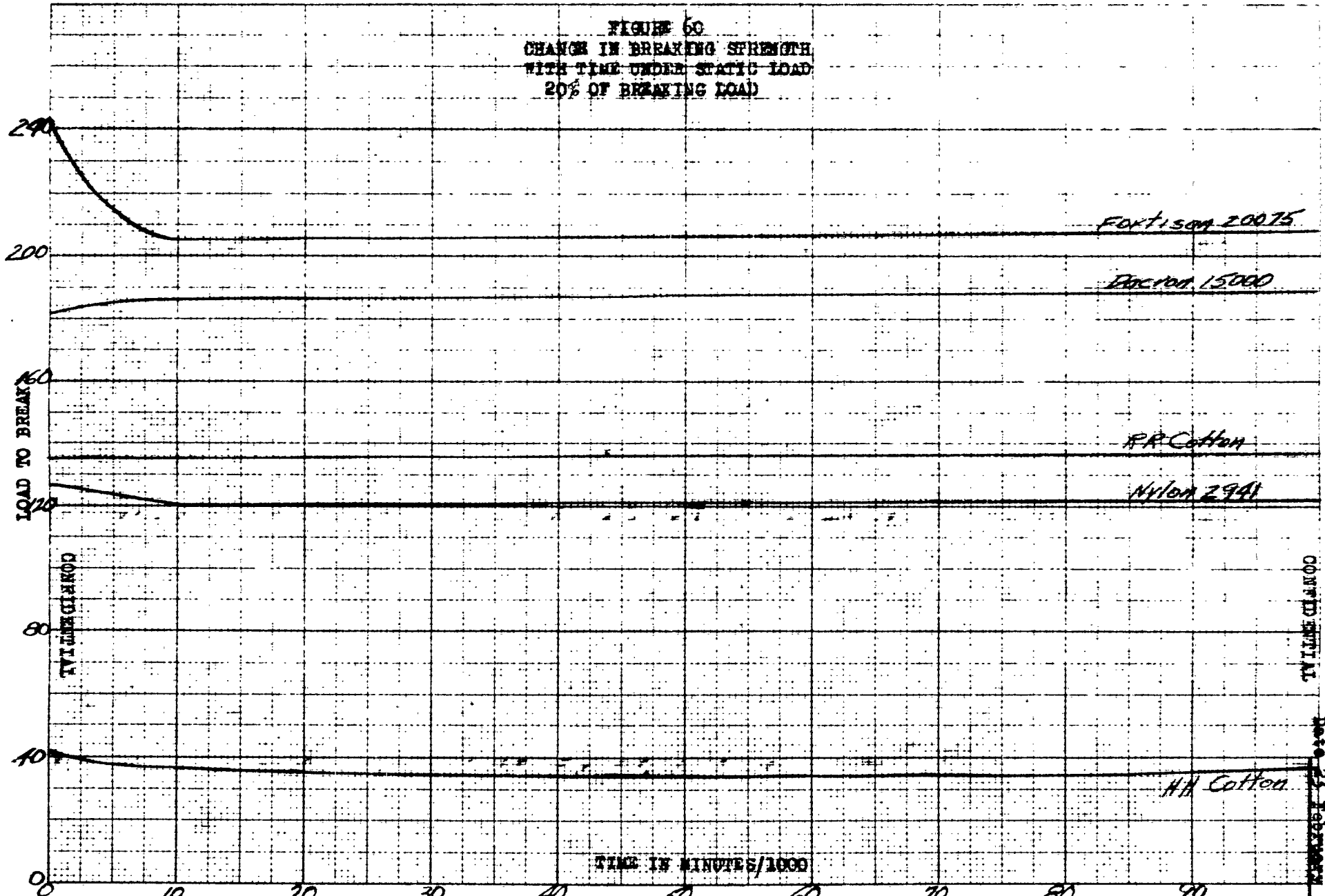
FIGURE 60
CHANGE IN BREAKING STRENGTH
WITH TIME UNDER STATIC LOAD
20% OF BREAKING LOAD



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5.3.1.6.4 Fourth Quarter

Curves on behavior under 20 ' load are given in Figures 61-71. These plots with time on a logarithmic scale emphasize changes during the first 100 days. Expansion of the length scale magnifies small changes, some of which may not be significant.

Many of the curves show relatively sudden increases in length of the samples. This may be due to breaking of fibers or of single yarns because of uneven distribution of load or because of weak points. An increase in load on the remaining yarns would occur and cause additional creep to take place.

Creep curves of the cotton fabrics used in making the 3 ply cotton envelope fabric are shown in Figure 61. RR cotton shows less creep than the others as well as a lower initial elongation. All the fabrics exhibit flatter creep curves after being heated for 30 minutes at 300° F.

Fortisan fabric curves are given in Figure 62. All the creep curves are quite flat and change little after heating the fabric.

Figure 63 shows creep curves of the old nylon fabrics. It emphasizes the difference between the behavior of greige nylon 2941 and the other nylon fabrics, all of which have been scoured or scoured and heat-set.

Figures 64, 65, and 66 show creep curves of later nylon fabrics. In each case the greige fabric has less creep than the scoured or the scoured and heat-set fabric. Two of the fabrics, 3142 and 3143, were heat-set in the greige with shrinkage prevented

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in both the warp and fill directions. The creep curves retained their shape. Also they changed little after heating the fabric for 30 minutes at 300° F.

Creep curves of the two old Dacron fabrics are shown in Figure 67. The curve for Dacron 15023 (type 5500) is remarkably flat.

The curves for Dacron 15023 fabric (type 5100) are given in Figure 68. There are large differences in initial elongation and in creep depending upon the finishing treatment. As with nylon fabrics, the greige Dacron fabrics exhibit the least creep. The curves change considerably after heating the fabrics at 300°F. for 30 mimutes. Heat-setting in the greige gives a fabric with a higher initial elongation than the original, but a curve with the same flat shape. Additional heating of the heat set fabric at 300° F. for 30 mimutes increased the initial elongation, but did not change the shape of the creep curve.

Figure 69 shows creep curves of Dacron 15020 fabrics (type 5500) which exhibit the same changes.

These creep curves of nylon and Dacron fabrics subjected to various treatments support the earlier idea that the best fabrics are those which have been heat-set in the greige and prevented as much as possible from shrinking in either direction.

Orlon fabrics creep as shown in Figure 70. Creep is excessive. No greige Orlon fabric was tested.

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Creep curves of plied fabrics are shown in Figure 71. The samples were loaded in the warp direction of the strongest fabric. The curves are essentially the same as those of the corresponding uncoated fabric. This is helpful to know. So far, no data is available on plied fabrics made from greige heat-set fabrics. The curves should be like those of the uncoated fabrics.

Specific parts of the creep data are summarized in Table XXII to enable comparisons to be made. In all cases, it takes at least ten days for the creep curve to flatten out.

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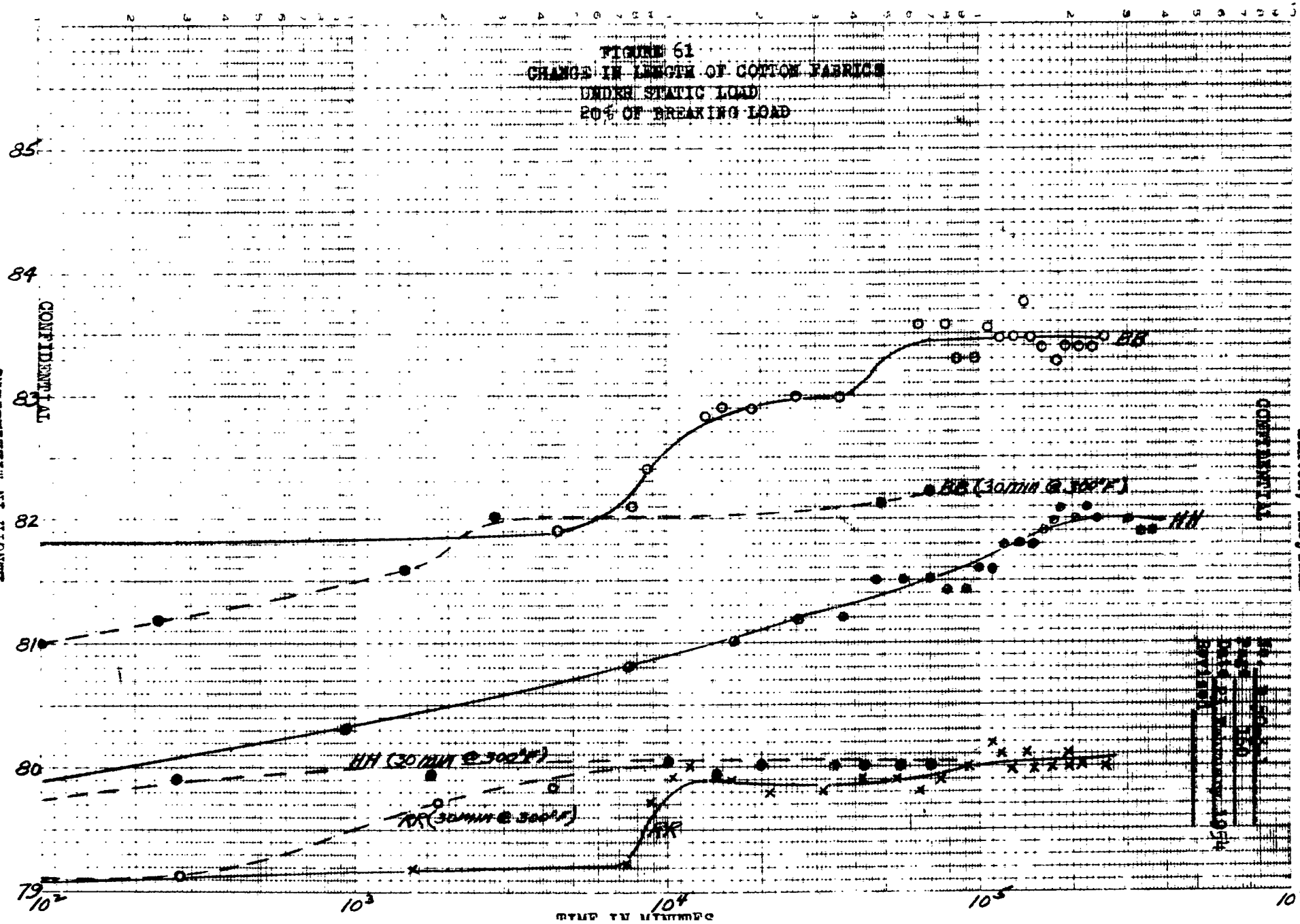
FIGURE 61
CHANGE IN LENGTH OF COTTON FABRICS
UNDER STATIC LOAD
20% OF BREAKING LOAD



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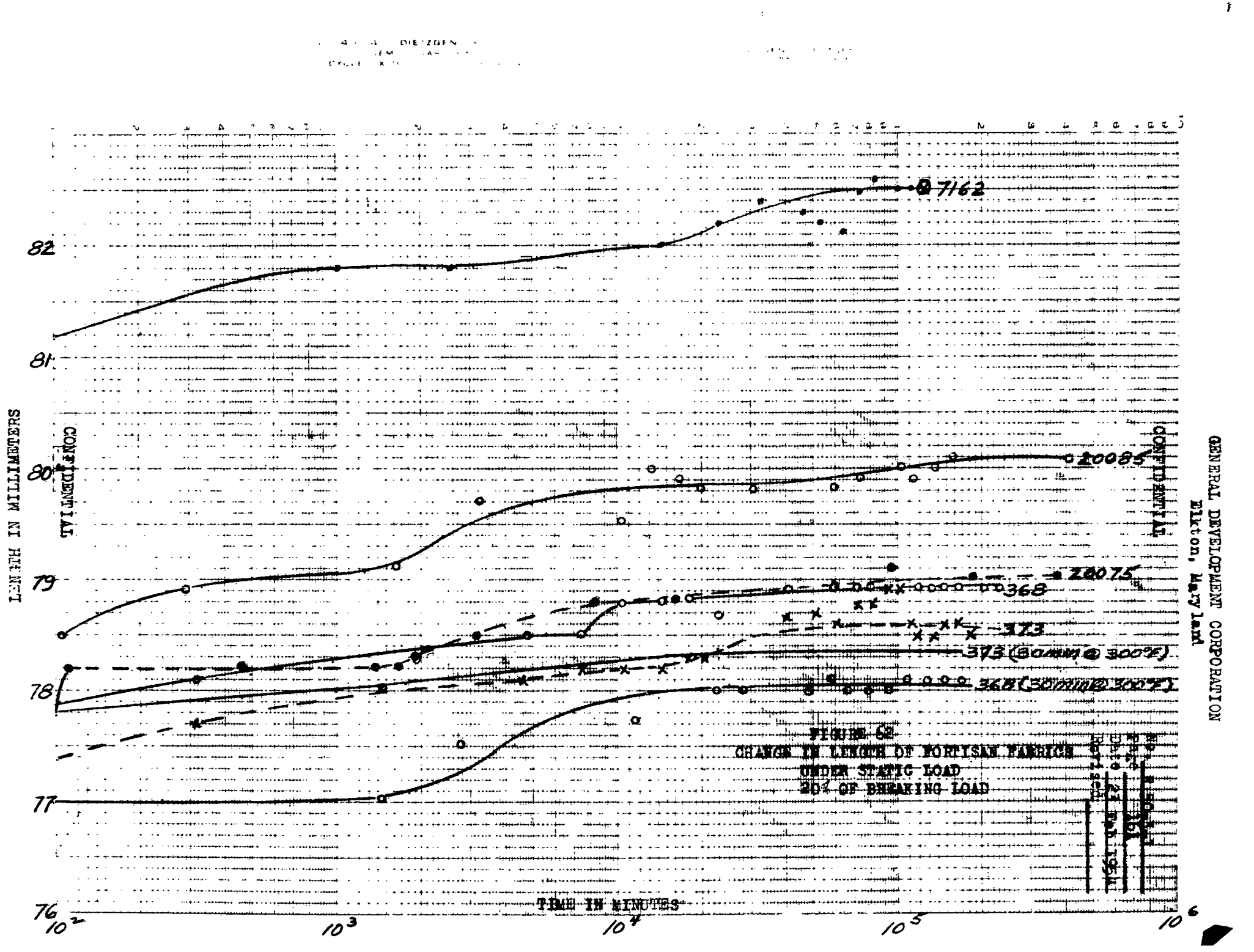

FIGURE 62
CHANGE IN LENGTH OF FORTISAN FABRICS
UNDER STATIC LOAD
20% OF BREAKING LOAD

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FIGURE 63
CHANGE IN LENGTH OF RIBBON FABRICS
UNDER STATIC LOAD
20% OF BREAKING LOAD

TIME IN MINUTES

LENGTH IN MILLIMETERS

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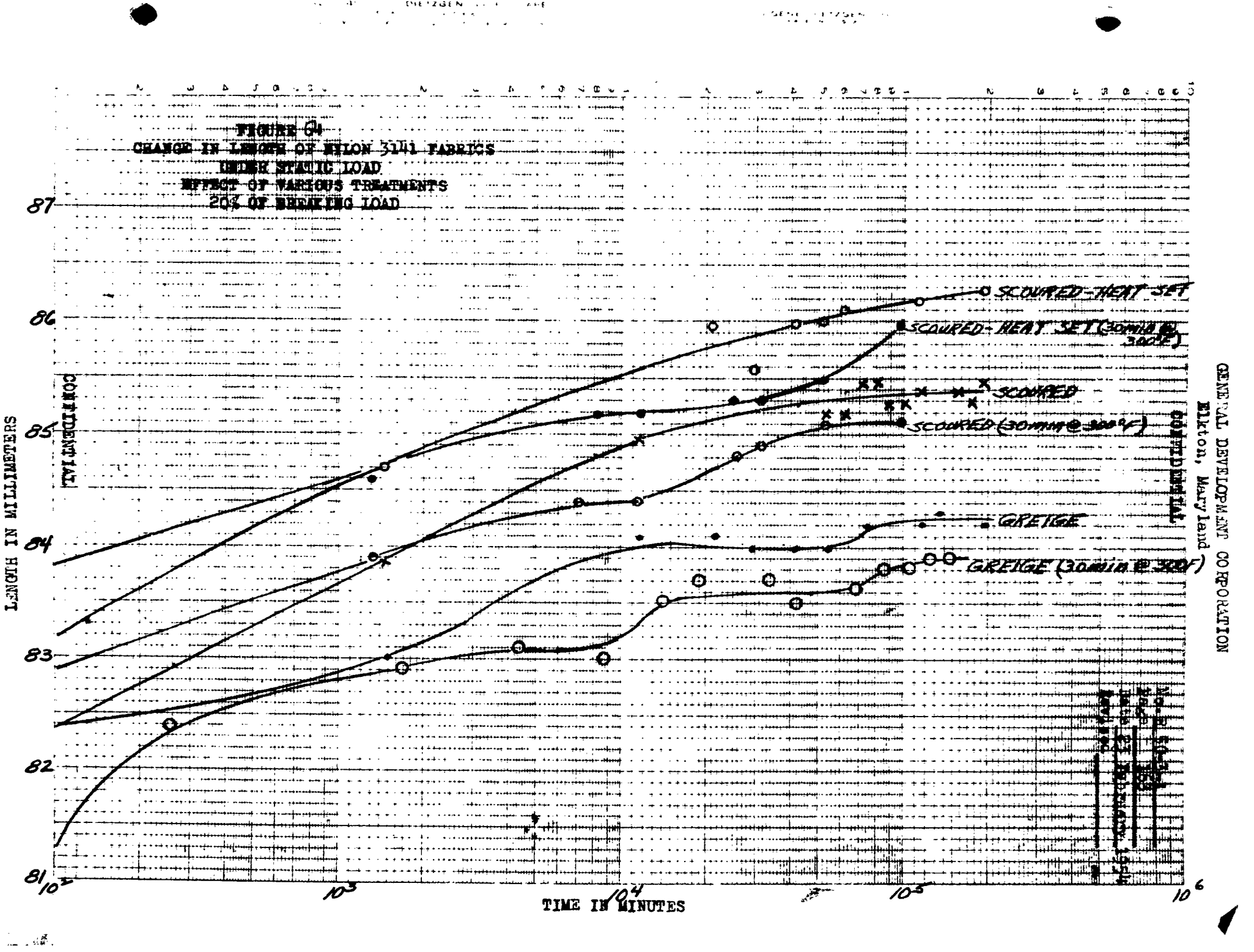
FIGURE 64
CHANGE IN LENGTH OF NYLON 3141 FABRICS
UNDER STATIC LOAD
EFFECT OF VARIOUS TREATMENTS
20% OF BREAKING LOAD
87
86
85
84
83
82
81
SCOURED-HEAT SET
SCOURED-HEAT SET (30 MIN @ 300°F)
SCOURED
SCOURED (30 MIN @ 300°F)
GREIGE
GREIGE (30 MIN @ 300°F)
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CHANGE IN LENGTH IN MILLIMETERS
TIME IN MINUTES
10^2
10^3
10^4
10^5
10^6
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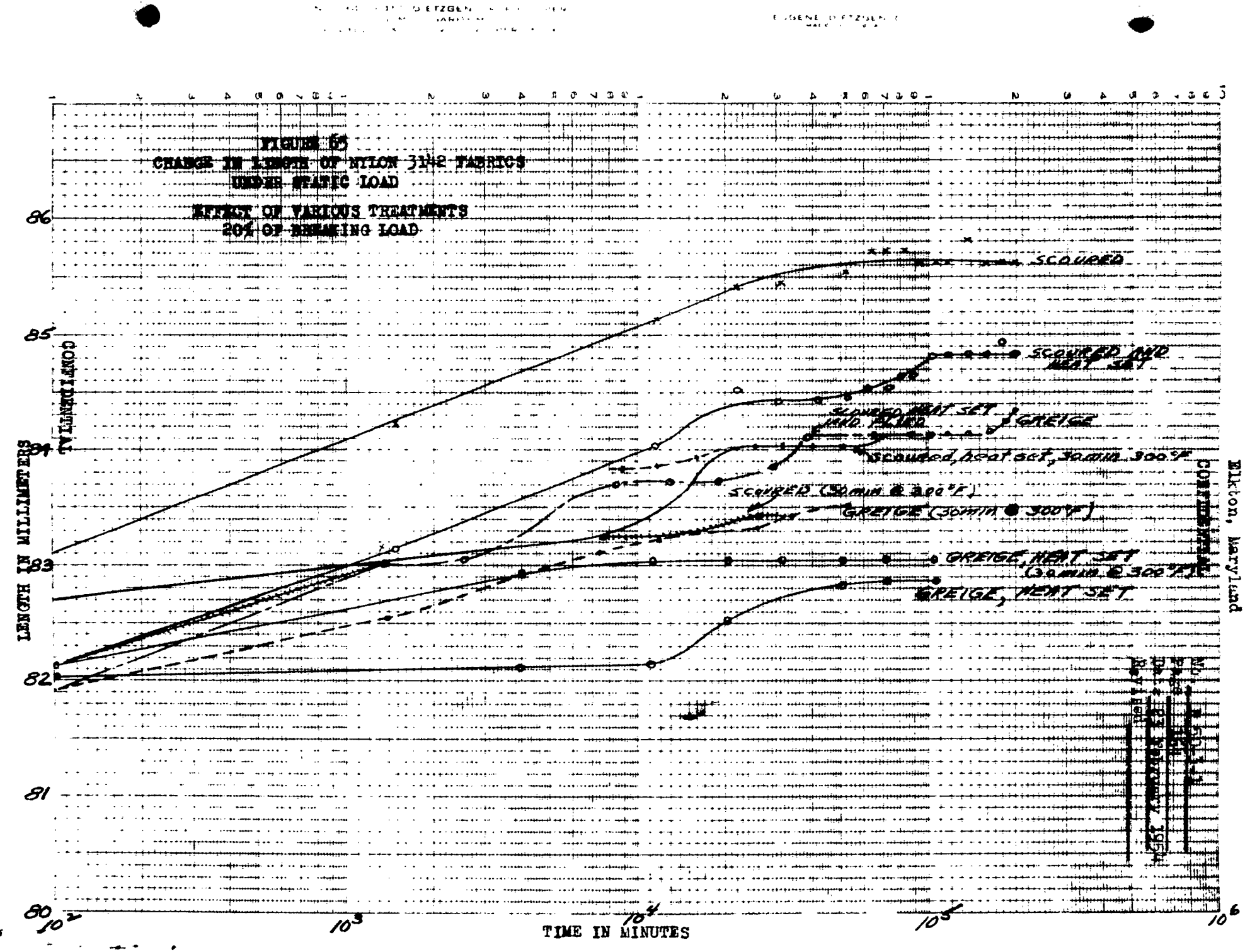
FIGURE 65
CHANGE IN LENGTH OF NYLON 3 1/2 FABRICS
UNDER STATIC LOAD
EFFECT OF VARIOUS TREATMENTS
20% OF BREAKING LOAD
LENGTH IN MILLIMETERS
CONTINUENTAL
86
85
84
83
82
81
80
SCOURED
SCOURED AND HEAT SET
SCOURED HEAT SET AND DYED
GREIGE
Scoured, heat set, 30 min 300°F
SCOURED (30 min @ 300°F)
GREIGE (30 min @ 300°F)
GREIGE, HEAT SET (30 min @ 300°F)
GREIGE, HEAT SET
10^2
10^3
10^4
10^5
10^6
TIME IN MINUTES
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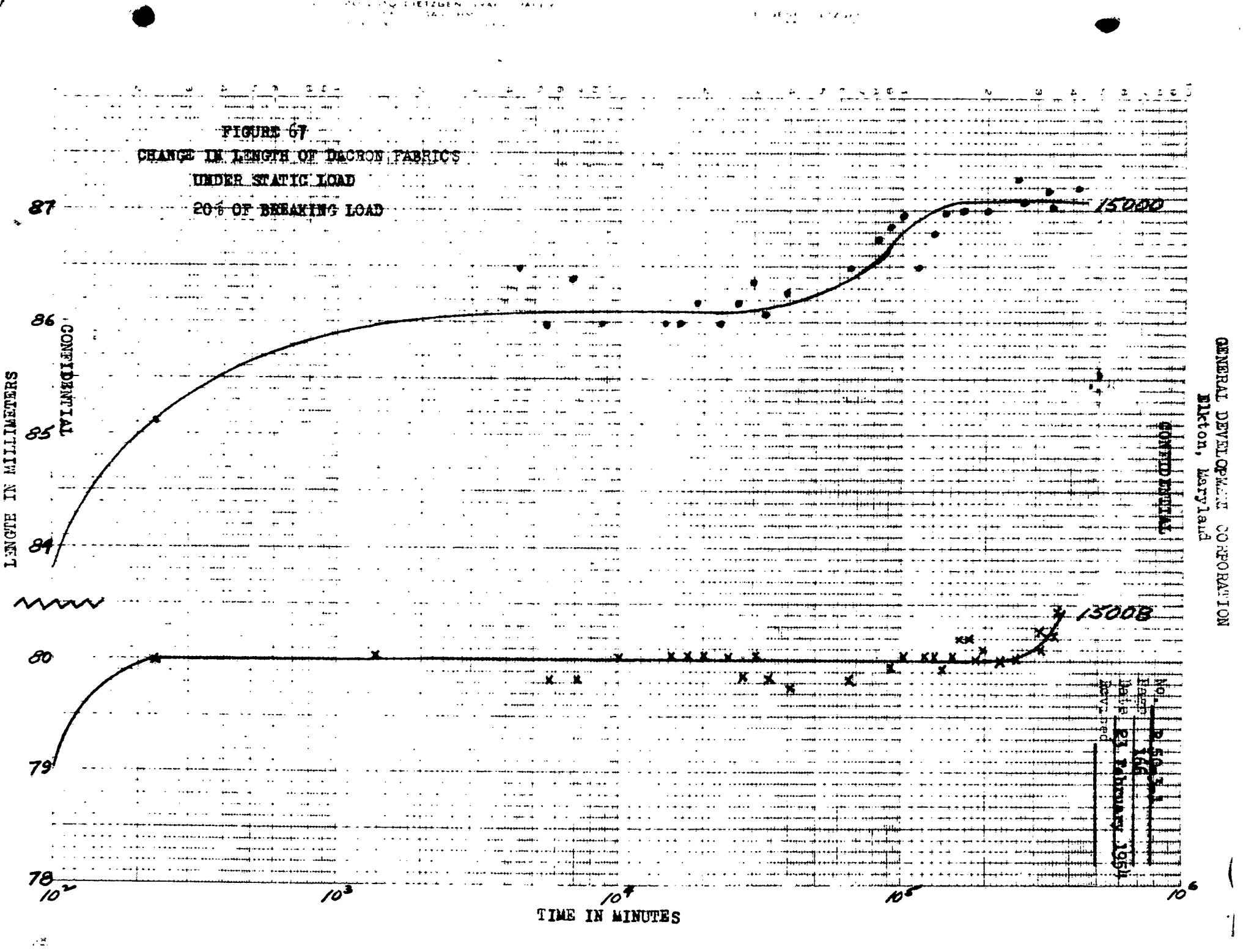
FIGURE 67
CHANGE IN LENGTH OF DACRON FABRICS
UNDER STATIC LOAD
20% OF BREAKING LOAD
87
86
85
84
80
79
78
15000
15008
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STRETCH IN INCHES
TIME IN MINUTES
10^2
10^3
10^4
10^5
10^6
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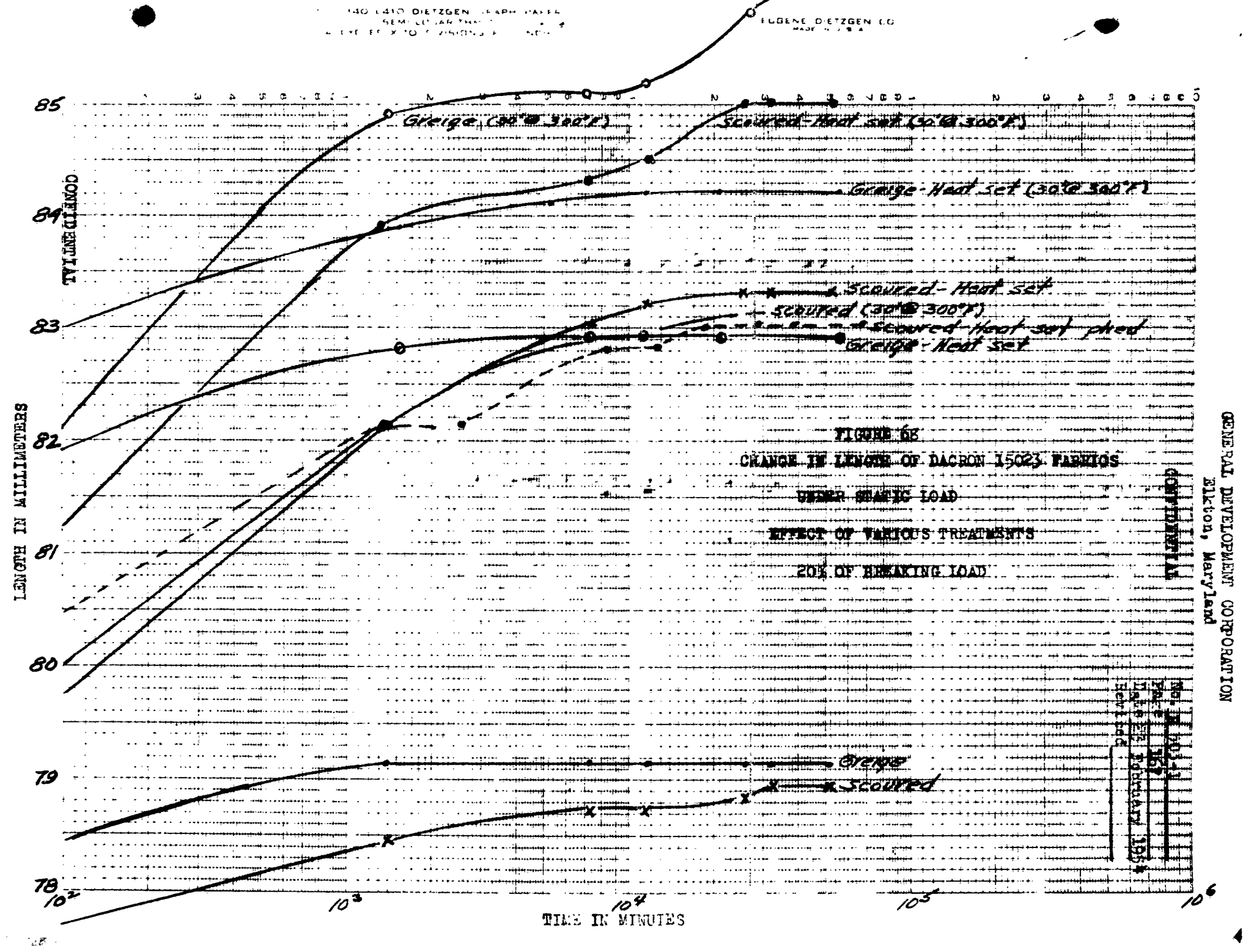

FIGURE 68

CHANGE IN LENGTH OF DACRON 15023 FABRICS

UNDER STATIC LOAD

EFFECT OF VARIOUS TREATMENTS

20% OF BREAKING LOAD

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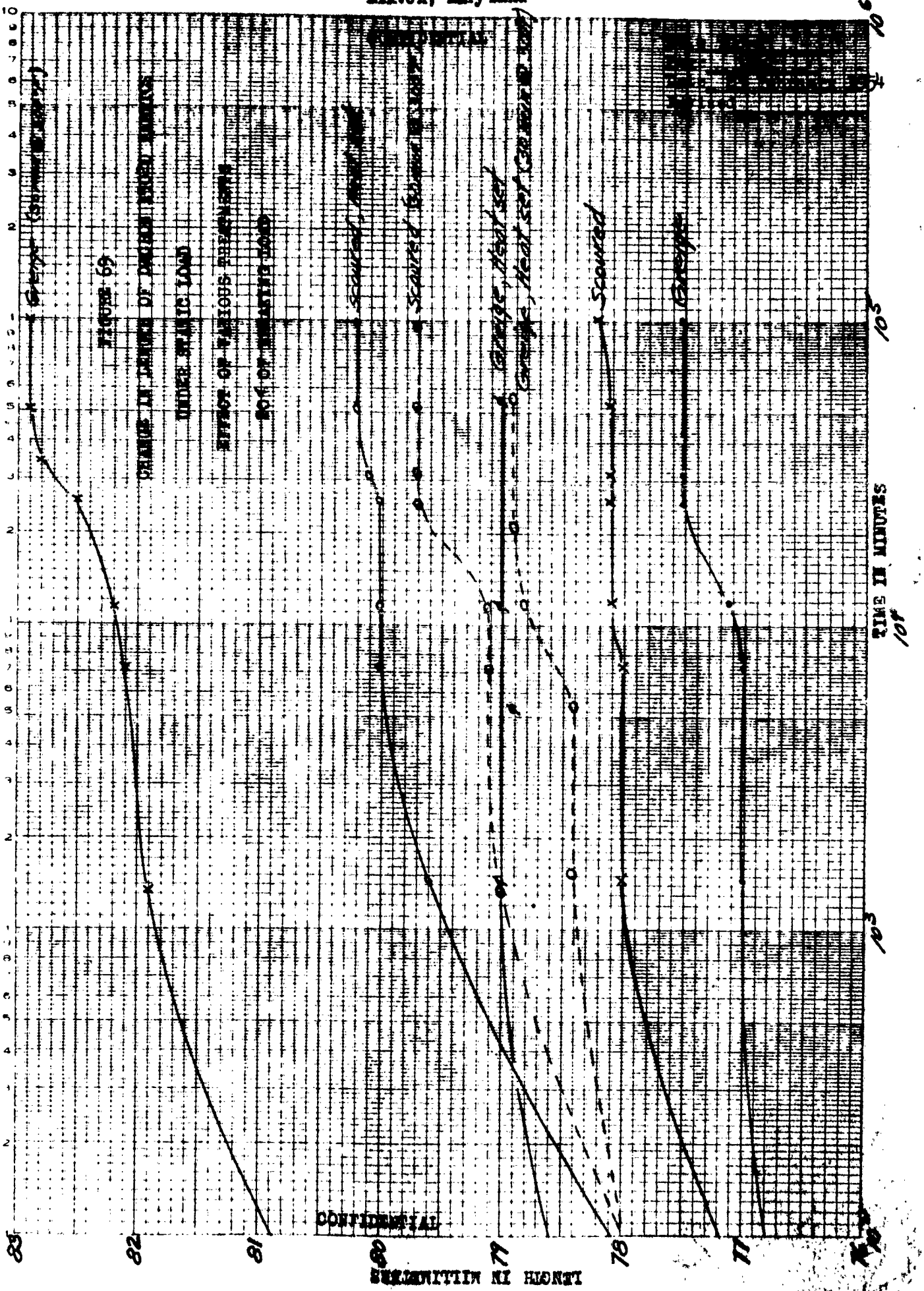

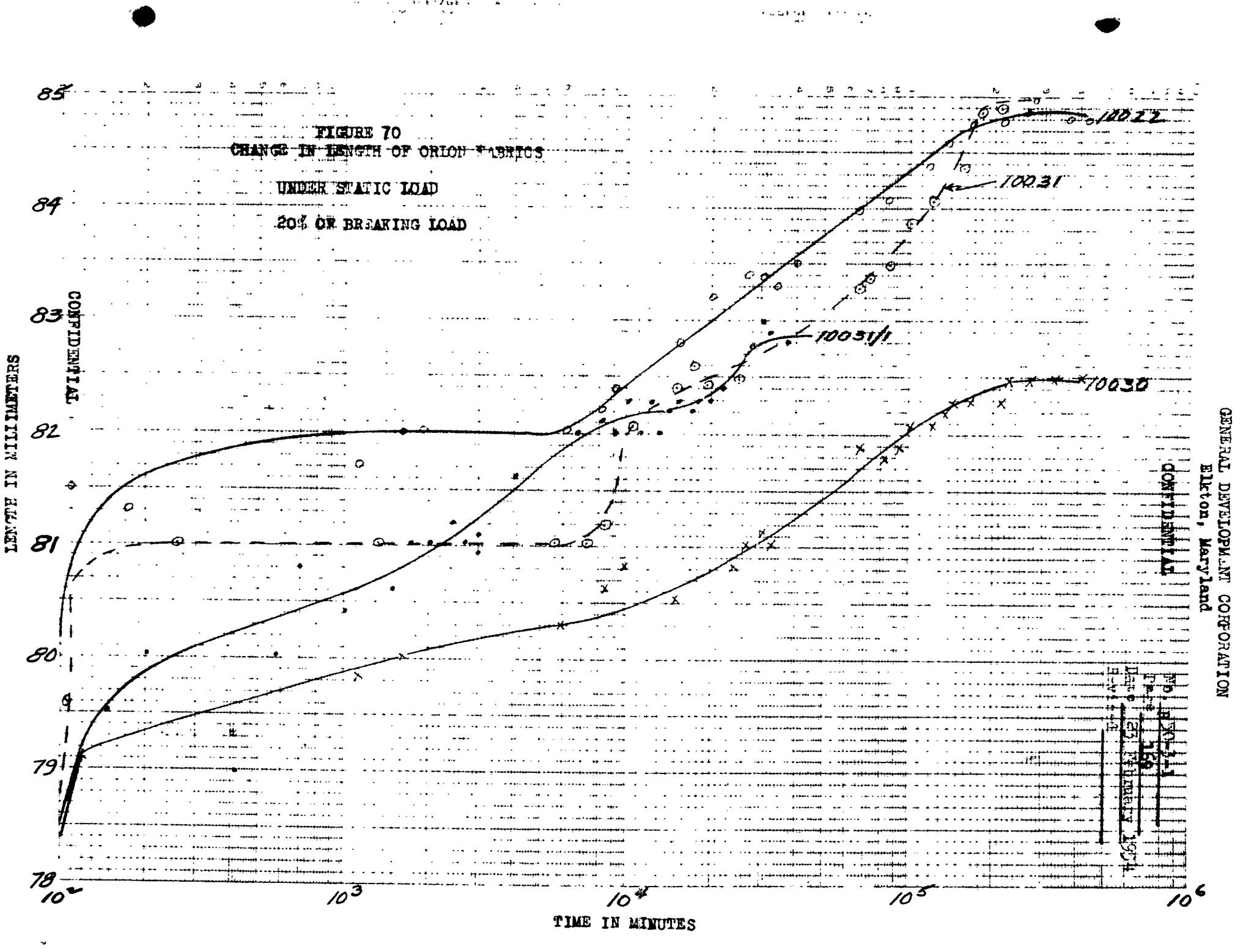
FIGURE 70
CHANGE IN LENGTH OF ORLON FABRICS
UNDER STATIC LOAD
20% OR BREAKING LOAD
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10022
10031
10031/1
10030
85
84
83
82
81
80
79
78
10^2
10^3
10^4
10^5
10^6
TIME IN MINUTES
STRETCH IN PERCENT
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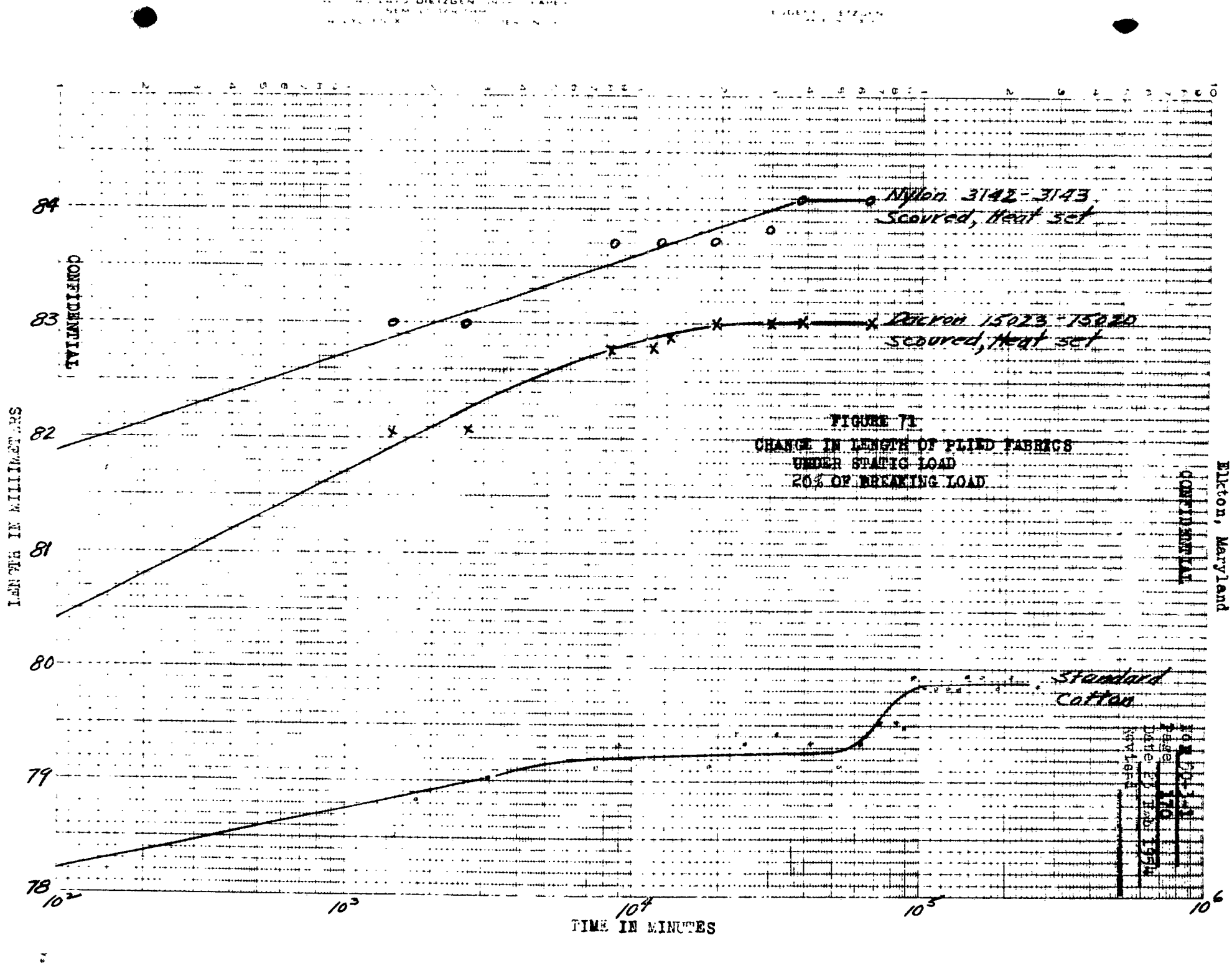

FIGURE 71
CHANGE IN LENGTH OF PLIED FABRICS
UNDER STATIC LOAD
20% OF BREAKING LOAD

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TABLE XXII. ELONGATION OF FABRICS UNDER STATIC LOAD OF 20 PERCENT OF BREAKING LOAD

Fabric	Percent Initial Elongation	Percent Elongation After 10 Days	100 Days	200 Days	300 Days
Cotton					
RR	3.9	5.0	5.3	5.3	
HH	5.0	6.6	7.8	7.9	
BB	7.6	8.9	9.9	9.9	
Fortisan					
7162	6.8	7.9	8.5		
20075	2.2	3.7	4.0	4.0	4.0
20085	3.2	5.0	5.3	5.4	5.4
368	1.3	2.6	3.8		
373	1.8	2.9	3.4		
Nylon					
2583/S	10.3	14.8	16.3	16.4	
2887	10.7	13.3	14.4	14.4	
2673/S	9.2	12.8	14.2	14.5	
2793	8.5	12.5	14.0	14.3	
2417	9.2	12.2	13.7	14.3	
2941	6.7	8.6	8.8	8.9	8.9
3141G	8.4	10.5	10.9		
3141S	8.4	11.9	12.3		
3141H	10.4	12.7	13.5		
3142G	8.3	10.1	10.5		
3142S	9.3	12.1	12.6		
3142H	8.9	10.7	11.6		
3142HB	7.9	8.1	8.9		
3143G	6.8	8.0	8.0		
3143S	7.9	9.6	9.8		
3143H	7.6	9.8	10.4		
3143HB	7.5	7.8			
Dacron					
15000	10.2	13.3	14.6	14.6	
15008	4.0	5.2	5.2	5.5	5.9
15023G	3.1	4.1	4.1*		
15023S	2.3	3.6	3.8*		
15023H	4.9	9.5	9.6*		
15023HB	7.8	10.8	10.8*		

*30 Days

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TABLE XXII. ELONGATION OF FABRICS UNDER STATIC LOAD OF 20 PERCENT OF BREAKING LOAD (continued)

Fabric	Percent Initial Elongation	Percent Elongation After 10 Days	100 Days	200 Days	300 Days
Orlon					
10029	4.6	8.8	11.4	11.7	11.7
10030	3.0	6.0	8.2	8.5	8.5
10031	2.7	8.3	10.8		
10031/1	3.3	5.9	8.1	8.9	8.9
Plied Nylon					
3142H †					
3143H	7.7	10.1			
Plied Dacron					
15020H †					
15023	5.8	9.1			
Standard Cotton	2.9	4.1	5.1	5.1	

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5.3.1.7 Change in Properties Under Load

A study of the change in tensile properties with time under static load was made. Information of this kind was felt to be applicable to determining what happens to an envelope fabric in use.

Samples were hung with static loads for different times and the change in length followed. The load was removed, the length of the sample measured, and then a tensile test was run. The results are given in Table XXIII.

Tensile strength and elongation both decrease with increasing time under load. The strength of nylon 2941 does not change much except under 60% load. Elongation is lower, however. The load-elongation curves are shown in Figure 72.

The strength of Dacron 15000 changes very little after being under load, but the elongation decreases also. Figure 74 shows the complete load-elongation curves.

RR cotton does not change much under 20% load, but decreases in strength under higher loads. HH cotton shows greater changes than RR cotton. The RR load-elongation curves are given in Figure 75.

The changes that take place with time under load are shown graphically in Figures 76 and 77 for breaking strengths.

Figure 78 shows the change in toughness index which relates the changes in strength and elongation. Dacron 15000 shows the greatest decrease numerically because of the large decrease in elongation. The toughness index cannot be compared

quantitatively for the different fabrics because of the difference in initial breaking strength. Percentage decrease is more significant, and this is greatest with Fortisan 20075. This would indicate that a Fortisan envelope fabric would be most susceptible to rupture under impact loads after being in use for some time.

The shape of the curves of strength versus time under load is somewhat indefinite because of the few points determined. More work is being done, and will be done, to obtain accurate data. The information available does indicate significant differences in behavior.

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TABLE XXIII. CHANGE IN PROPERTIES OF FABRICS UNDER STATIC LOAD

Fabric	Load	Time in Mins.	Initial	Final	Load Off	Tensile Strength Lbs	Percent Elongation	Toughness Index
2941	0%	0				128	21.6	13.8
	20%	10,000	8.2	9.2	3.9	122	16.0	9.8
		50,000	7.8	9.3	3.8	122	16.2	9.9
	40%	1,905	10.5	11.8	3.2	126	16.0	10.1
		14,000	10.7	12.5	3.5	127	15.7	10.0
	60%	985	13.1	13.8	1.9	119	18.0	10.7
		2,975	12.5	14.4	2.8	111	18.3	10.2
		5,775	13.1	16.2	3.9	108	18.3	9.9
15000	0%	0				184	27.0	24.8
	20%	10,000	8.5	11.8	9.3	168	19.1	16.1
		50,000	9.8	13.3	10.5	188	16.7	15.7
	40%	1,920	15.7	16.5	10.6	181	16.0	14.5
		15,810	15.7	16.7	11.4	169	15.0	12.7
	60%	975	18.4	19.7	11.9	187	13.0	12.2
		1,910	17.2	19.8	11.8	188	12.0	11.3
20075	0%	0				245	8.3	10.3
	20%	10,000	3.8	5.1	3.8	204	5.7	5.8
		50,000	3.2	5.2	4.3	208	3.8	3.9
	40%	1,735	5.6	5.8	3.9	228	4.3	4.9
		2,985	5.3	5.9	2.9	213	6.0	6.4
	60%	5,775	4.4	5.6	2.9	194	5.5	5.3
		120	6.3	7.2	3.5	222	6.3	7.0

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TABLE XXIII. CHANGE IN PROPERTIES OF FABRICS UNDER STATIC LOAD (continued)

Fabric	Load	Time In Mins	Initial	Final	Load Off	Tensile Strength Lbs	Percent Elongation	Toughness Index
RR	0%	0				136	4.6	3.1
	20%	10,000	3.2	3.8	2.6	134	4.8	3.2
		50,000	4.3	5.1	3.9	137	3.7	2.5
	40%	1,905	4.9	5.5	3.9	142	4.0	2.8
		10,010	4.4	5.4	3.3	125	4.0	2.5
	60%	990	5.5	5.9	2.9	126	4.3	2.7
		2,500	5.2	5.7	2.8	123	4.3	2.6
HH	0%	0				45	7.3	1.6
	20%	10,000	4.9	6.5	5.8	37	5.3	0.98
		50,000	5.2	6.9	6.4	33	4.0	0.66
	40%	1,915	6.8	7.8	5.9	33	3.3	0.55
		5,855	7.2	9.5	7.8	27	2.3	0.31
	60%	33	8.5	8.5	5.8	33	3.3	0.55
		60	8.5	8.9	6.2	37	4.0	0.64

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TABLE XXIV. EFFECT OF TEMPERATURE ON PHYSICAL PROPERTIES OF UNCOATED FABRICS

Fabric	Time Mins.	Temp. of	Tensile lbs/in.	Elongation, % Break	Elongation, % 20	Tear lbs.
HH	--	--	45	7.7	2.0	4.4
	15	250	41	7.6	3.3	4.7
	30	250	41	7.0	2.7	4.7
	60	250	46	7.3	3.0	5.2
	15	300	41	7.6	3.3	5.1
	30	300	40	8.3	3.3	5.4
	60	300	34	7.6	2.7	4.8
	15	350	37	7.3	3.3	4.5
	30	350	36	7.3	3.0	3.7
	60	350	29	7.0	2.5	3.4
RR	--	--	136	6.0	1.5	52.6
	15	250	137	6.7	1.7	54.2
	30	250	142	6.3	2.0	50.2
	60	250	136	7.0	2.3	55.2
	15	300	137	6.3	2.0	50.8
	30	300	140	6.7	2.3	52.2
	60	300	140	6.7	2.3	50.6
	15	350	134	7.0	2.0	50.0
	30	350	134	6.7	1.7	52.4
	60	350	139	6.0	1.7	45.6
20075	--	--	232	9.0	1.1	47.0
	15	250	248	7.7	1.7	
	30	250	239	8.3	2.0	
	60	250	231	8.7	2.3	
	15	300	182	9.3	1.7	
	30	300	200	8.3	1.7	
	60	300	197	7.3	1.3	
15000	--	--	184	27.3	3.0	89.9
	15	250	185	27.3	4.0	86.0
	30	250	180	26.6	4.0	86.2
	60	250	190	25.6	4.0	85.2
	15	300	190	27.3	4.7	81.0
	30	300	182	28.3	4.3	80.0
	60	300	188	28.3	4.3	85.0
	15	350	177	31.9	4.3	80.8
	30	350	181	33.3	4.7	82.6
	60	350	188	32.6	4.3	82.4

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TABLE XXIV. EFFECT OF TEMPERATURE ON PHYSICAL PROPERTIES OF UNCOATED FABRICS (cont)

Fabric	Time Mins	Temp. of	Tensile Lbs/Ins.	Elongation, % Break	Elongation, % 20%	Tear Lbs
2941	--	--	128	21.6	6.5	53.5
	15	250	125	24.6	8.0	46.6
	30	250	110	24.3	8.0	45.2
	60	250	115	24.3	7.7	44.4
	15	300	122	26.6	8.0	53.6
	30	300	124	26.6	7.7	57.8
	60	300	121	26.6	7.7	62.2
	15	350	121	27.3	6.7	66.0
	30	350	108	26.6	7.0	56.4
	60	350	81	22.3	3.0	46.4
2950	--	--	233	26.3	8.0	97.9
	15	250	200	33.0	8.7	98.2
	30	250	233	33.6	9.7	114.0
	60	250	195	30.0	7.7	111.8
	15	300	226	35.0	9.3	101.0
	30	300	201	33.6	7.3	102.2
	60	300	235	38.0	9.7	115.4
	15	350	210	37.0	6.7	105.0
	30	350	217	37.2	7.7	97.2
	60	350	198	32.9	6.7	80.4
2116	--	--	266	37.7		177.0
	15	250	247	37.3		175.0
	30	250	222	33.3		184.6
	60	250	177	32.3		179.8
	15	300	228	34.0		176.0
	30	300	248	41.3		187.0
	60	300	212	41.0		179.4
	15	350	228	40.0		206.0
	30	350	238	43.0		167.0
	60	350	229	38.3		102.2

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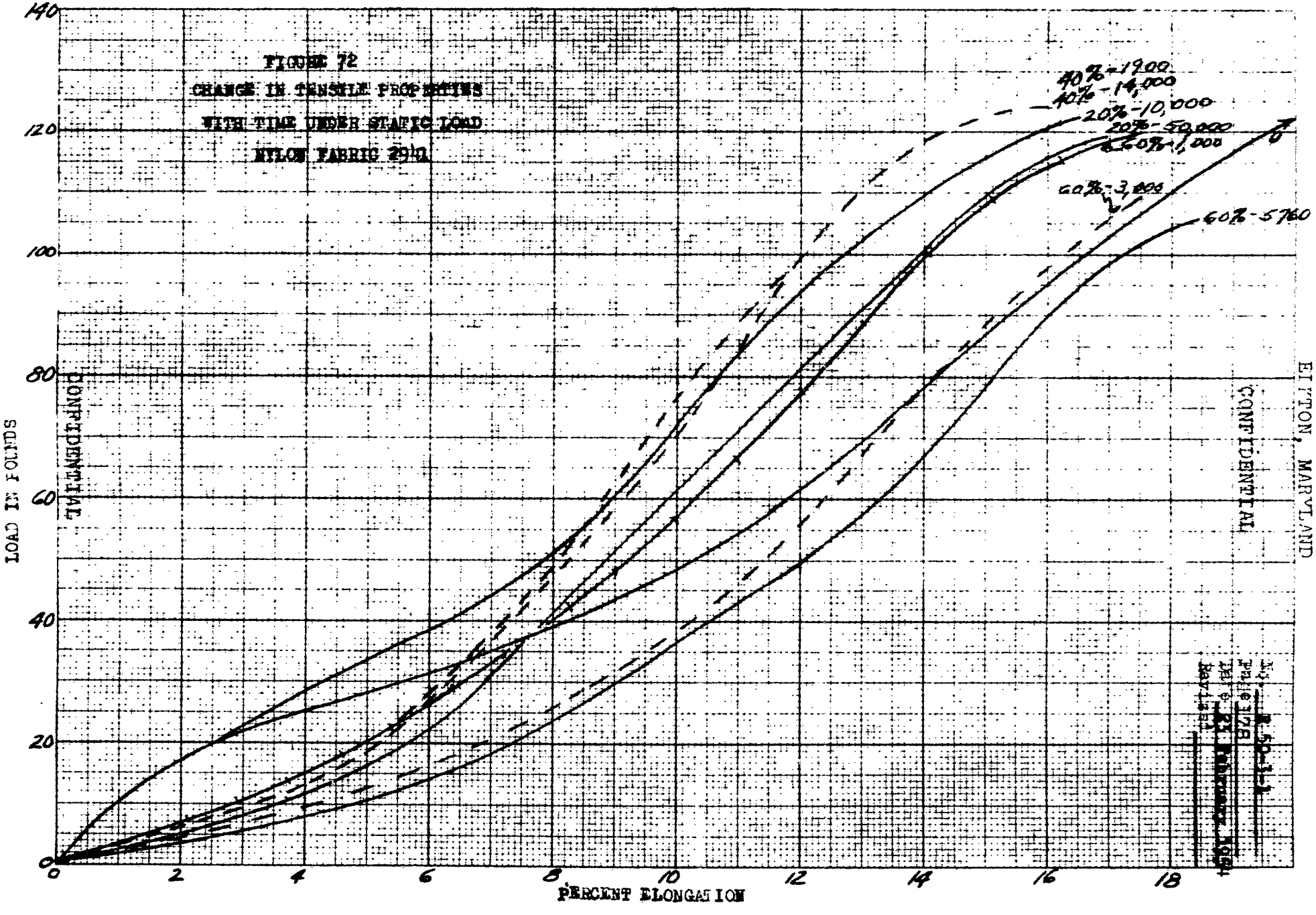

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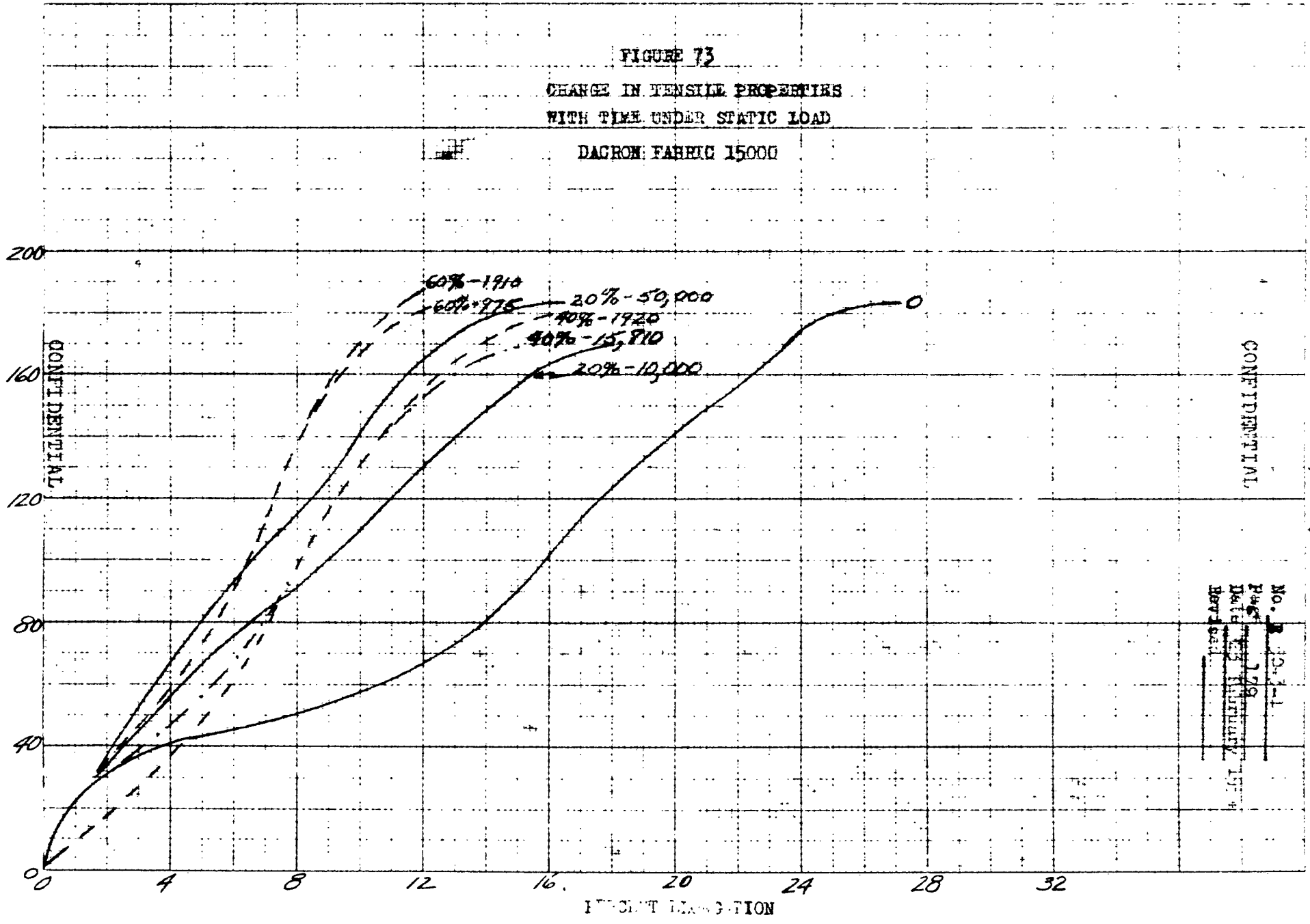
FIGURE 73

CHANGE IN TENSILE PROPERTIES
WITH TIME UNDER STATIC LOAD

DACRON FABRIC 15000



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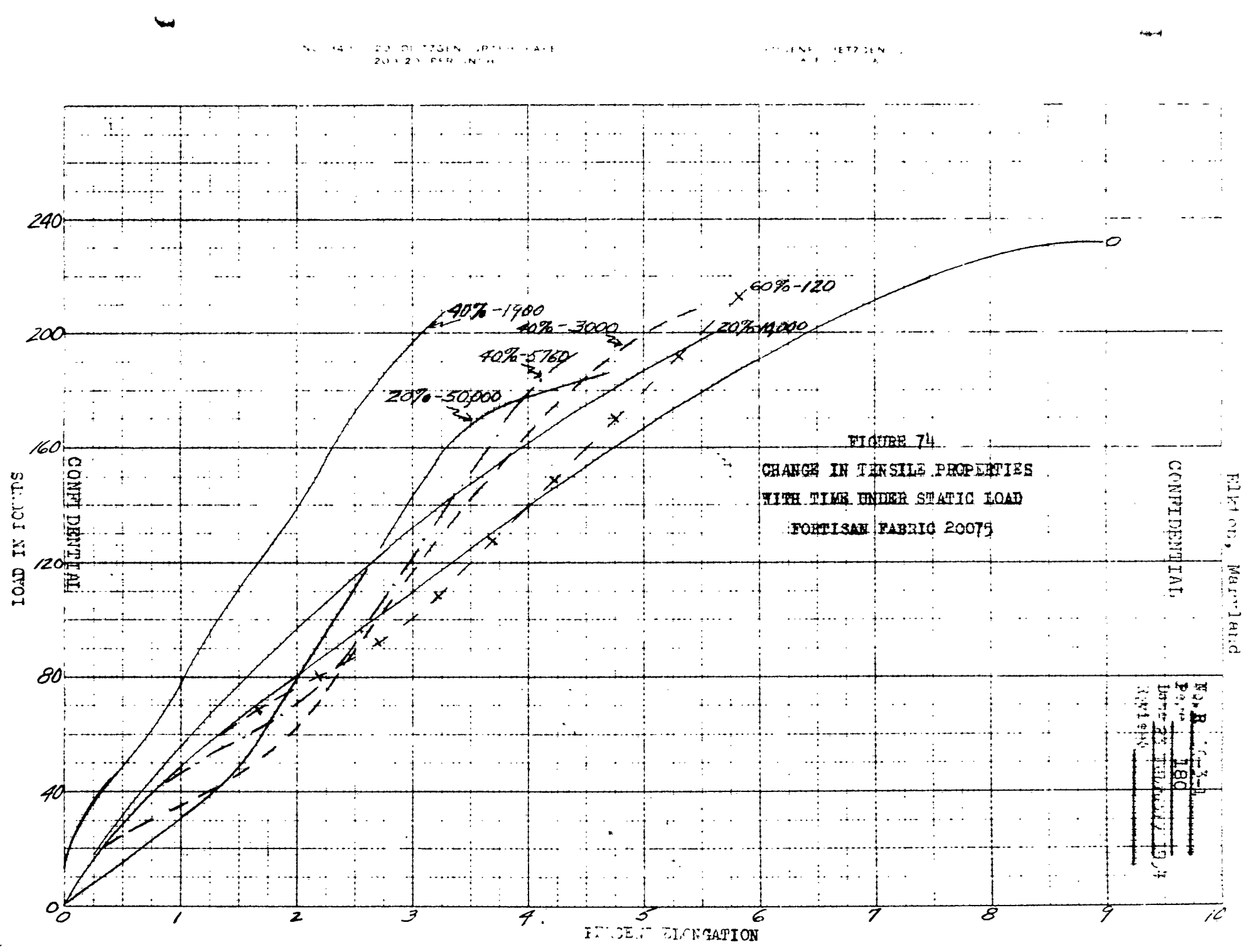

FIGURE 74

CHANGE IN TENSILE PROPERTIES WITH TIME UNDER STATIC LOAD

FORTISAN FABRIC 20075

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FIGURE 75

CHANGE IN TENSILE PROPERTIES
WITH TIME UNDER STATIC LOAD
COTTON FABRIC 5013 (ER)

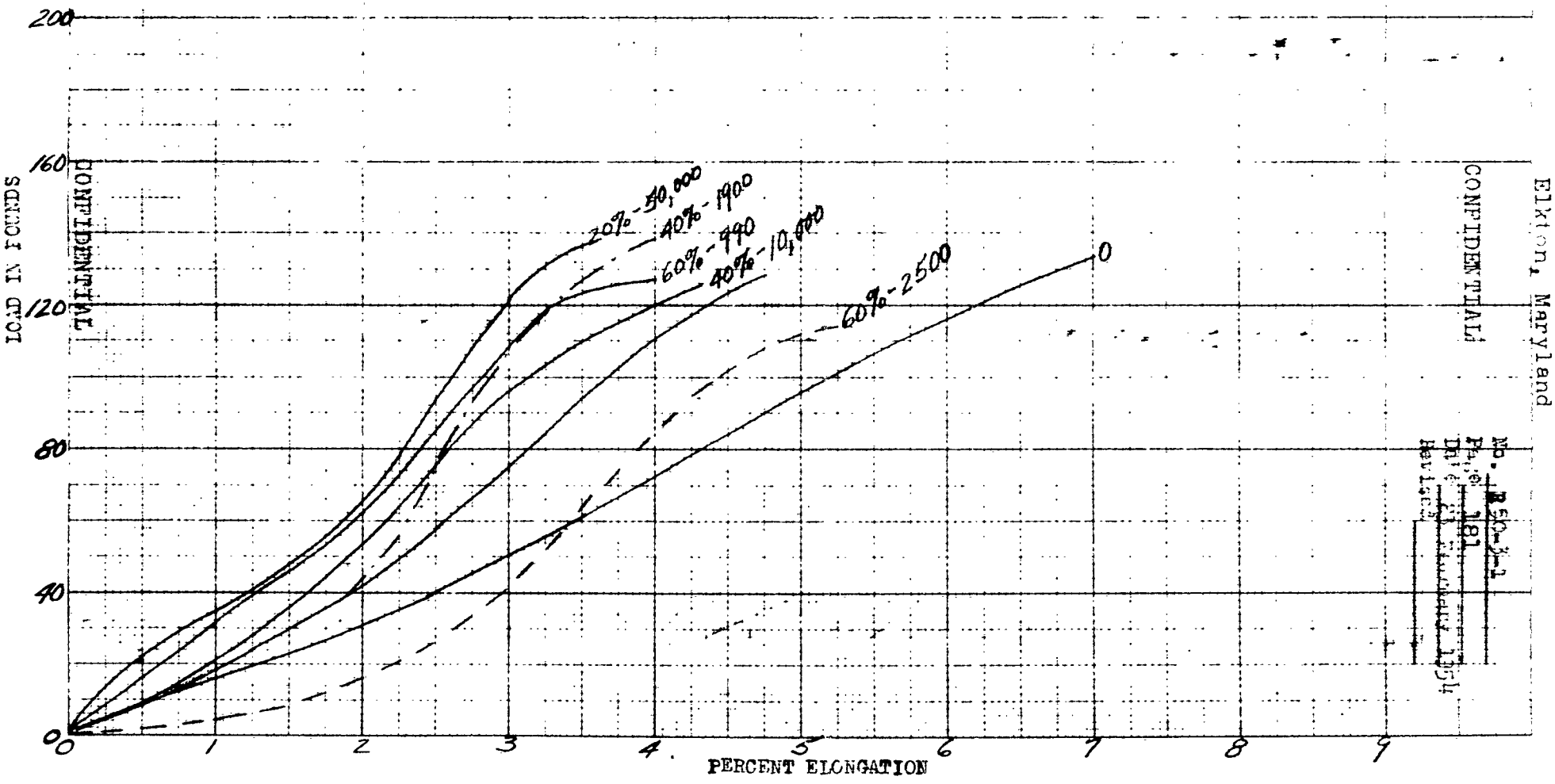

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FIGURE 76

CHANGE IN BREAKING STRENGTH

WITH TIME UNDER STATIC LOAD

20% OF BREAKING LOAD

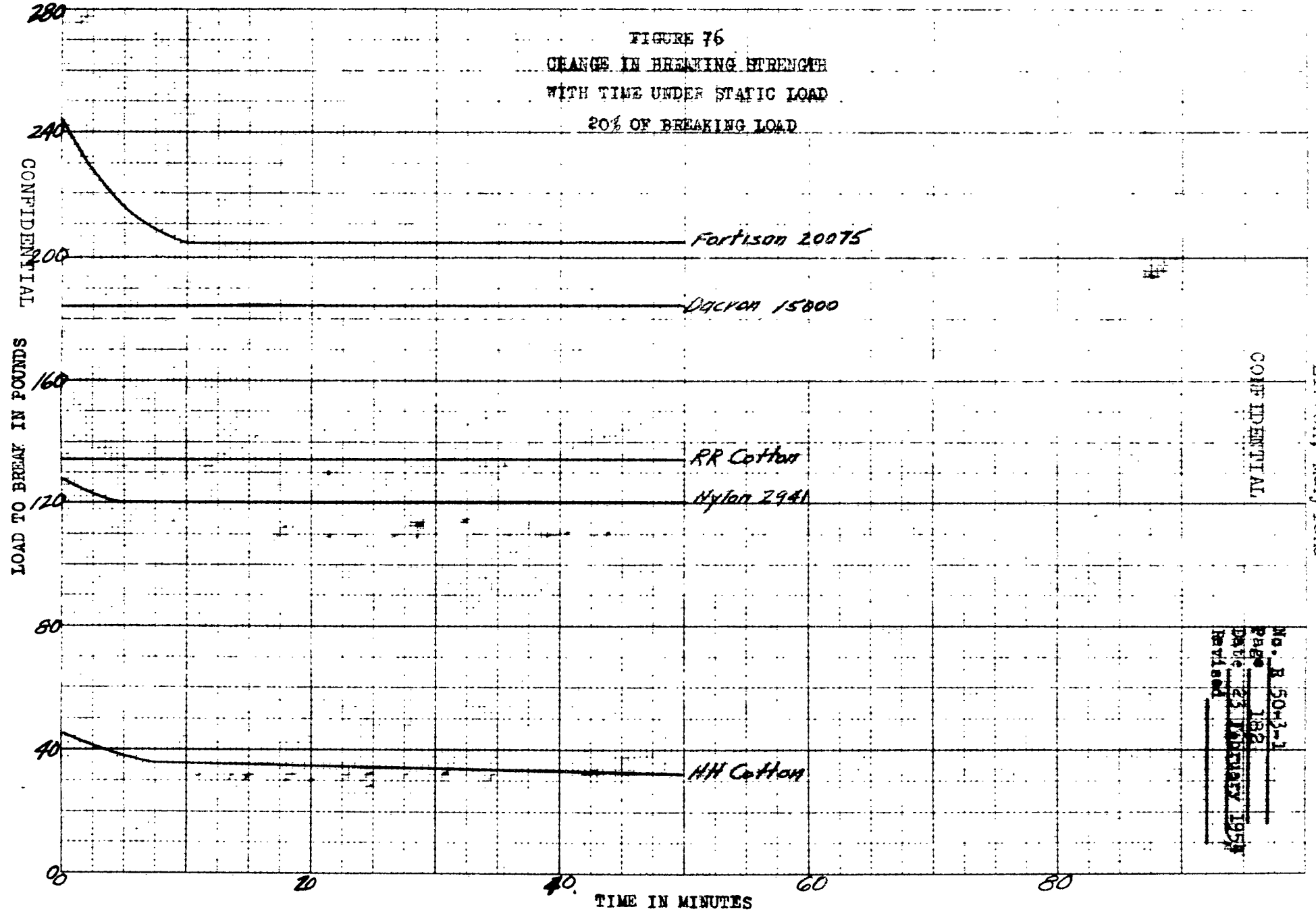

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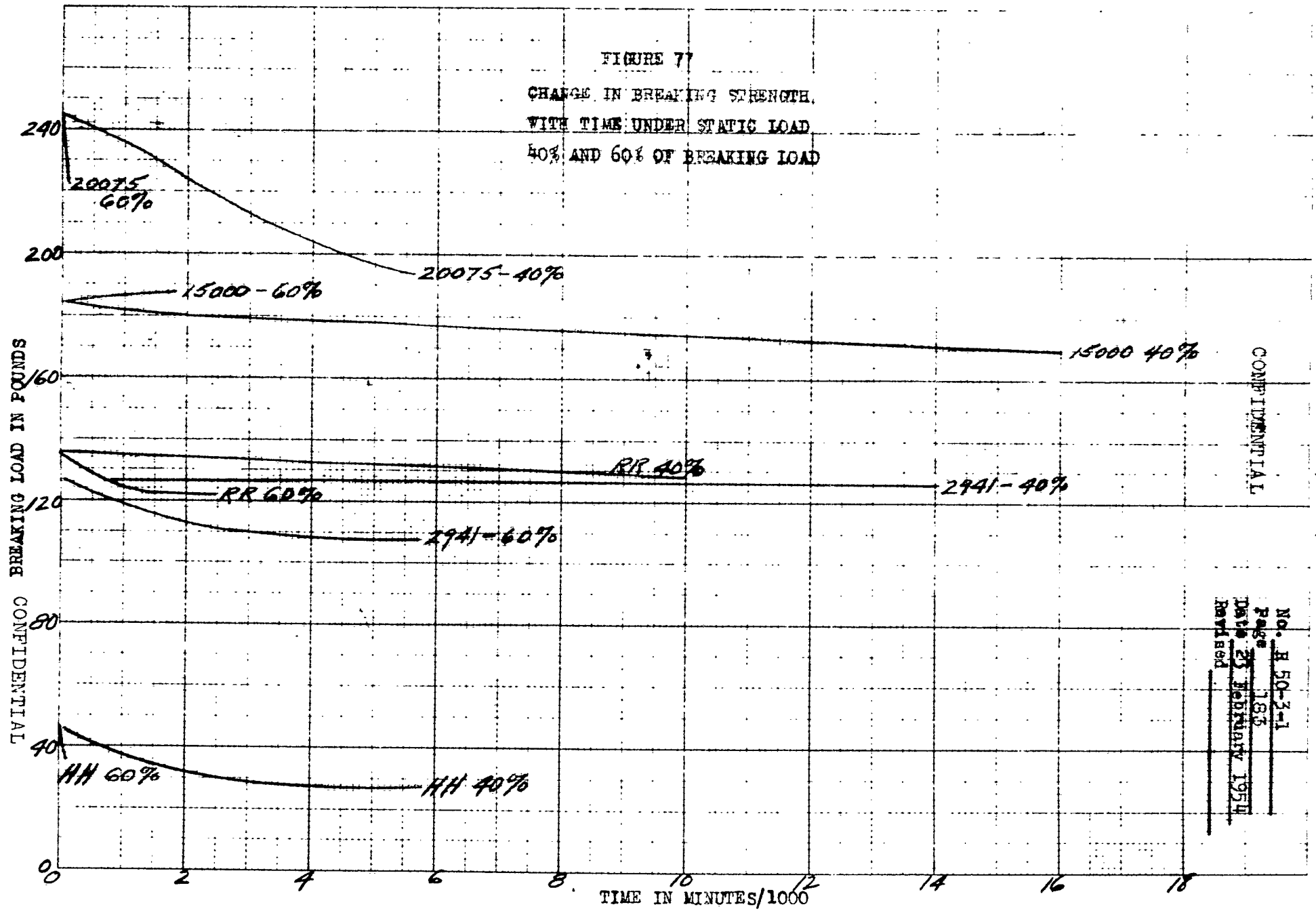
FIGURE 77

CHANGE IN BREAKING STRENGTH WITH TIME UNDER STATIC LOAD 40% AND 60% OF BREAKING LOAD



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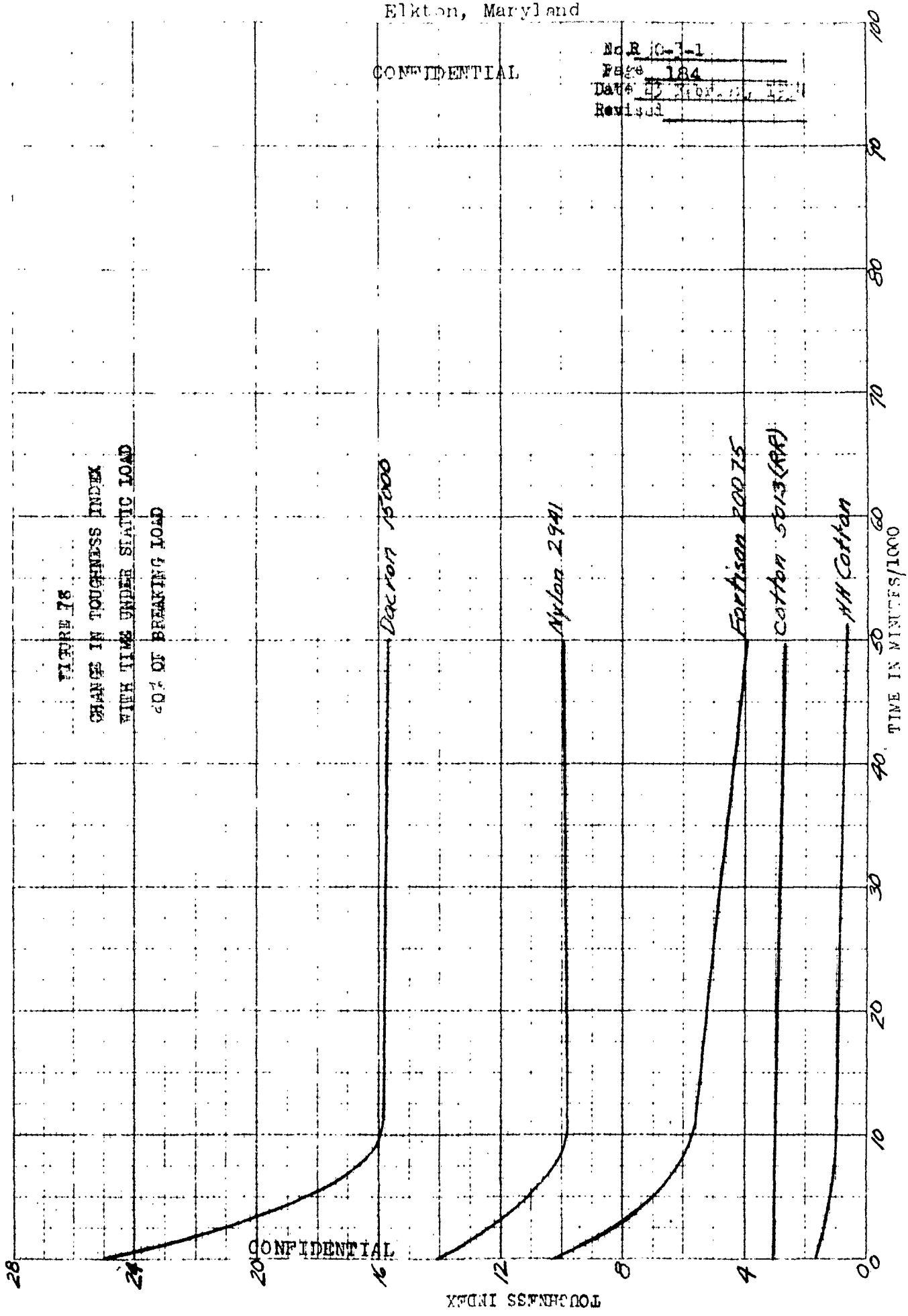

FIGURE 78
CHANGE IN TOUGHNESS INDEX
WITH TIME UNDER STATIC LOAD
20% OF BREAKING LOAD

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5.3.1.8 Effect of Heat

A study was made to determine the effect of temperatures in the curing range of Neoprene, on the properties of the fabrics. Nylon and Dacron fabrics are known to degrade if exposed to temperatures of around 300° F. for too long a time. If appreciable changes did take place during curing of the Neoprene, then data on unheated fabrics would not be applicable to the coated product.

The results on the effect of heat are given in Table XXIV.

Cotton fabrics HH and RR do not change much in tensile or elongation on heating. The HH cotton loses strength after heating an hour at 350°F. RR cotton has been mercerized which may account for the difference in behavior.

Fortisan suffers a considerable loss in strength after heating. Not enough of the 20075 fabric was available to carry out tests at 350°F. Elongation decreases after heating.

The three nylon samples all show a large drop in strength for the longer times at all temperatures. Degradation is shown also by the decrease in elongation.

It is interesting to note that elongation at 20% of the breaking strength increases for Fortisan and cotton fabrics although the ultimate elongation either changes very little or decreases. For the Dacron and nylon fabrics, both

elongations increase.

Tear strength as described under section 3.1.5, of the cotton fabrics does not change much except after heating for longer times at 350°F., when it decreases.

Tear strength of Dacron 15000 decreases about a maximum of 11% of the original value.

The nylon fabrics increase in tear strength and then decrease. This follows roughly the increase and decrease in elongation.

Nylon fabric 2116 is a 3 ply mesh fabric having a high tear strength. It is too heavy (7.41 oz per sq. yd) for use in envelopes. Its tensile strength is 398 lbs. which gives a strength weight ratio of 862.

The results on the effect of temperature on physical properties of fabrics are shown graphically in Figures 79, 80, and 81.

Thus temperature has pronounced effects on the physical properties of some fabrics. Measurement of these effects is important because of the changes which may occur during cure of the Neoprene coating at elevated temperatures. Samples of the fabrics were heated at different temperatures for varying periods of time and their properties measured. Only one nylon sample was treated completely in order to reduce the number of tests. It was assumed that the other nylon fabrics would behave in the same manner. Five duplicate samples were run for each test. The results are given

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in Table XXV and shown graphically in Figure 82 for tensile strength, and Figure 83 for tear strength.

Tensile strength of all fabrics decrease with increasing temperature. Nylon 3141 loses the most strength over the temperature range studied. The greige fabric loses strength at lower temperatures than the scoured or heat-set fabrics. This is not so for the other nylon fabrics and, therefore, may be an erroneous result.

Many tensile strength results on RR cotton are lower than expected. This is not due to degradation, but to difficulties in testing. The standard ravelled strip tensile test requires the use of a sample one inch wide held in one inch jaws. In many cases the yarns on the edges slip in the jaws, resulting in a low tensile figure. More consistant results were obtained with three inch jaws. The curve for RR cotton in Figure 82 is plotted from earlier results.

The data shows that the normal curing schedule for Neoprene of 30 minutes at 300°F. causes loss in strength of HH cotton, BB cotton, Fortisan 373 and nylon 3141 greige. The other fabrics lose strength rapidly at temperatures above 300°F. The coating, however, may modify these results if degradation is due to oxidation rather than to heat alone. The main increase in elongation occurs in the greige nylon fabrics. The special heat set nylon 3142 HB retains its low elongation after heating.

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Tear strengths also drop with increasing temperature except for RR cotton. HH cotton and BB cotton do not change much in tear strength. Fortisan 373 shows a very large decrease beginning at 275°F. or less. The Fortisan twill 368 loses much less strength.

The nylon fabrics lose tear strength very rapidly above 300°F. This shows again that this should be the maximum temperature for cure, assuming that the coating has no protective effect.

Fabric weights and strength-weight ratios were determined. The results are included in Table XXV. The greatest change in weight occurs in the greige nylon fabrics. The heat-set nylon, Fortisan, and cotton fabrics show no change.

All the Dacron fabrics were heated in an oven and their properties determined. These are listed in Table XXVI. Heating causes increases in tensile strength, elongation, and tear strength, which are greatest for the greige fabrics and least for the scoured, heat-set fabrics.

Strength-weight ratios decrease after heating. The ratios of the greige fabrics decrease the most; while the ratios of the scoured, heat-set fabrics decrease very little.

Dimensional stability, as measured by changes in weight per square yard, is highest for the scoured, heat-set fabrics.

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All these points favor the use of heat-set fabrics.

The greige, nylon and Dacron fabrics which had been heat-set with shrinkage restrained in the warp and fill directions, also were heated. Their properties before and after heating are listed in Table XXVII. All the properties change very little after heating.

The properties of the original greige nylon fabrics and the heat-set greige fabrics are almost identical. The greige Dacron fabrics could not be restrained completely from shrinking. The weight after treatment is higher. Tensile strength, elongation, and tear strength are higher. With the proper equipment, heat-setting without change in properties, except heat stability, should be possible.

These heat-set greige fabrics appear to be the most desirable for airship envelope fabrics. Permeability for a given weight of coating may be decreased. This will be investigated.

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TABLE XXV . EFFECT OF HEATING ON PHYSICAL PROPERTIES OF UNCOATED FABRICS

Fabric	Time Mins.	Temp. °F.	Tensile Strength Lbs/Ins.	Elongation %	Tear Strength Lbs.	Weight Oz/Sq.Yd	Strength Weight Ratio
RR Cotton	--	--	137.0x130.0	3.2x5.2	53.2x56.4	5.15	426x387
	15	250	110.8x96.2	6.0x5.6	55.3x58.5	5.1	350x303
	30	250	102.4x120.6	5.1x6.2	57.1x57.0	5.2	315x371
	60	250	138.2x130.4	5.1x5.1	59.4x56.8	5.2	425x401
	15	300	111.6x114.8	6.1x5.5	56.4x58.5	5.2	343x351
	30	300	125.8x111.6	4.8x5.3	61.2x58.6	5.1	397x352
	60	300	128.2x109.8	4.3x5.1	58.2x54.2	5.1	404x346
	15	350	127.2x118.4	5.1x5.3	64.2x64.0	5.2	391x365
	30	350	137.6x119.4	4.7x5.0	59.4x53.8	5.1	434x377
	60	350	140.0x122.6	4.5x4.5	55.4x62.2	5.1	442x387
HH Cotton	--	--	41.5x39.8	8.5x12.9	4.4x5.0	1.95	341x327
	15	250	36.8x37.8	5.8x10.7	2.6x2.5	1.95	293x310
	30	250	35.4x39.3	5.8x11.3	2.5x2.3	1.95	290x321
	60	250	36.3x39.7	5.9x9.9	2.4x2.2	1.95	293x325
	15	300	33.4x37.8	5.5x10.9	2.4x2.3	1.9	281x319
	30	300	34.3x36.3	5.4x9.5	2.3x2.7	1.9	289x306
	60	300	31.7x35.7	5.2x9.7	2.3x2.1	1.9	267x300
	15	350	31.3x34.3	5.3x9.5	2.7x2.7	1.95	254x280
	30	350	29.3x33.0	4.3x7.5	2.3x2.3	1.95	243x271
	60	350	23.1x29.0	4.9x5.1	2.2x2.4	1.9	237x290
RR Cotton	--	--	34.4x35.3	12.3x12.3	5.0x4.8	2.3	368x375
	15	250	31.4x33.4	12.1x12.7	5.4x5.3	2.3	351x391
	30	250	34.4x31.8	9.3x11.5	4.4x4.1	2.35	305x347
	60	250	37.3x33.2	9.3x11.1	4.3x4.3	2.3	329x321
	15	300	34.2x30.0	11.9x12.1	4.6x4.1	2.85	304x337
	30	300	32.0x31.4	10.3x11.1	4.2x4.2	2.8	297x351

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TABLE XXV. EFFECT OF HEATING ON PHYSICAL PROPERTIES

OF UNCOATED FABRICS - SHEET TWO

Fabric	Time Mins.	Temp. °F	Tensile Strength Lbs/In.	Elongation %	Tear Strength Lbs.	Weight Oz/Sq. Yd.	Strength Weight Ratio
BB Cotton Cont'd	60	300	52.2x57.1	10.1x10.9	4.6x4.2	2.9	288x315
	15	350	52.8x63.2	9.9x10.6	4.7x4.3	2.8	302x353
	30	350	52.0x61.8	9.7x10.5	4.5x4.3	2.95	282x335
	60	350	50.0x57.0	10.1x10.1	4.0x3.9	2.9	276x309
Fortisan 368	--	--	116.6x130.0	6.9x8.7	13.3x13.0	2.2	848x945
	15	250	118.8x130.8	7.7x9.5	13.7x15.5	2.1	905x998
	30	250	118.0x135.0	6.8x8.5	12.1x12.7	2.1	900x1030
	60	250	117.0x124.0	7.1x8.1	11.5x12.3	2.15	870x922
	15	300	99.0x102.0	6.7x8.3	10.3x10.6	2.1	755x778
	30	300	119.2x135.2	6.8x8.9	10.0x10.7	2.1	908x1030
	60	300	110.0x111.0	6.2x7.8	10.0x10.3	2.05	859x868
	15	350	102.2x113.4	6.7x9.0	7.6x7.8	2.1	779x865
	30	350	106.6x114.2	7.0x10.7	7.5x7.3	2.1	813x870
	60	350	103.4x114.2	6.1x8.0	6.5x6.3	2.1	788x870
Fortisan 373	--	--	201.8x178.8	7.1x7.4	41.4x35.3	3.6	897x795
	15	250	195.8x190.8	6.7x8.8	32.9x26.7	3.5	894x871
	30	250	200.4x199.0	7.0x7.3	34.7x25.3	3.6	892x884
	60	250	197.0x193.0	6.9x7.6	28.3x27.4	3.55	888x869
	15	300	192.4x172.2	5.8x5.8	20.9x18.7	3.55	868x776
	30	300	186.4x175.6	6.2x6.8	21.9x18.2	3.5	850x802
	60	300	179.6x177.8	5.8x6.3	20.4x18.2	3.5	820x811
	15	350	198.4x186.2	6.1x6.6	20.3x17.7	3.5	906x850
	30	350	183.6x181.8	5.9x6.3	19.5x17.8	3.55	828x819
	60	350	186.0x177.2	5.9x6.7	17.5x16.3	3.55	838x798

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TABLE XXV. EFFECT OF HEATING ON PHYSICAL PROPERTIES OF UNCOATED FABRICS - SHEET THREE

Fabric	Time Mins	Temp. °F.	Tensile Strength Lbs/In.	Elongation %	Tear Strength Lbs	Weight Oz/Sq.Yd	Strength Weight Ratio
Nylon 3141 Greige	--	---	210.0x222.6	23.8x21.3	77.9x94.3	3.7	908x966
	15	250	184.9x205.6	24.9x25.1	78.5x111.2	3.85	769x856
	30	250	181.6x206.4	26.3x27.0	76.8x101.3	3.85	756x859
	60	250	187.4x201.2	27.0x25.2	79.1x91.9	3.95	759x815
	15	300	189.6x215.4	29.3x31.4	81.6x90.6	4.1	740x842
	30	300	190.0x196.2	31.3x33.5	76.2x90.4	4.05	752x776
	60	300	165.2x180.8	32.7x30.7	75.4x81.2	4.05	653x715
	15	350	166.4x167.2	24.2x23.1	59.0x58.2	4.2	633x637
	30	350	140.4x153.2	21.4x20.9	45.0x49.4	4.1	548x598
	60	350	120.6x128.4	20.2x20.9	37.6x41.1	4.1	471x502
Nylon 3141 Scoured	--	---	233.4x234.0	29.7x35.3	88.3x91.8	4.05	922x925
	15	250	234.4x223.4	29.7x31.4	72.1x76.6	4.1	915x872
	30	250	238.0x230.8	31.4x34.1	72.2x73.1	4.1	930x901
	60	250	238.2x232.2	32.6x35.2	74.8x78.9	4.1	930x907
	15	300	238.4x246.2	32.3x34.1	71.3x79.6	4.2	909x937
	30	300	233.4x232.8	33.2x35.0	70.8x72.3	4.2	889x887
	60	300	235.2x235.0	32.6x33.8	78.0x80.8	4.2	897x895
	15	350	212.8x210.2	31.7x31.5	60.0x56.0	4.3	792x782
	30	350	138.4x187.6	28.7x28.7	52.3x47.7	4.3	700x698
	60	350	132.8x133.7	27.7x25.0	38.0x34.0	4.25	501x503
Nylon 3141 Scoured and Heat-Set	--	---	235.4x234.4	38.6x37.5	98.3x92.5	4.35	836x862
	15	250	226.0x236.6	33.9x36.7	76.3x71.7	4.35	832x870
	30	250	236.2x240.0	35.9x37.1	75.7x75.6	4.35	869x883
	60	250	237.2x234.2	36.5x38.1	78.9x74.3	4.35	873x862
	15	300	228.4x243.2	36.4x39.3	79.6x76.4	4.35	840x894
	30	300	235.0x237.2	35.4x36.2	73.5x73.9	4.35	864x872

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TABLE XXV. EFFECT OF HEATING ON PHYSICAL PROPERTIES OF UNCOATED FABRICS - SHEET FOUR

Febric	Time Mins.	Temp. °F.	Tensile Strength Lbs/In	Elongation %	Tear Strength Lbs	Weight Oz/Sq.Yd	Strength Weight Ratio
Nylon 3141 Scoured & Heat-Set	60	300	230.4x232.0	34.7x35.5	72.6x77.5	4.35	848x853
	15	350	210.6x209.4	33.1x33.8	62.2x61.9	4.35	774x769
	30	350	180.2x165.4	28.9x28.7	60.0x45.5	4.35	663x608
	60	350	138.4x135.4	24.9x26.1	35.9x32.6	4.35	509x498
Nylon 3142 Greige	--	---					
	30	300	187.0x197.0	21.8x22.9	81.6x80.8	3.4	840x885
			192.4x208.4	25.7x28.3	83.3x95.2	3.7	832x902
Nylon 3142 Scoured	--	---					
	30	300	195.0x192.0	28.2x34.3	91.9x84.4	3.7	845x832
			202.6x208.4	28.5x33.8	76.5x78.0	3.85	842x867
Nylon 3142 Scoured & Heat-Set	--	---					
	30	300	192.5x196.0	32.1x40.7	97.0x95.7	4.0	780x784
			201.0x196.5	31.8x35.3	90.6x75.3	3.95	814x797
Nylon 3142 Heat-Set	--	---					
	30	300	187.2x187.2	24.4x26.1	81.4x81.8	3.55	843x843
			181.4x201.0	21.8x24.1	77.0x80.2	3.55	818x906
Nylon 3143 Greige	--	---					
	30	300	128.6x127.8	21.1x22.6	24.5x27.7	2.45	838x834
			131.6x130.2	24.2x29.6	24.0x24.5	2.65	794x786
Nylon 3143 Scoured	--	---					
	30	300	143.6x127.2	26.8x36.0	31.1x31.9	2.6	842x745
			147.4x126.4	36.9x37.5	29.0x30.6	2.75	858x735
Nylon 3143 Scoured & Heat-Set	--	---					
	30	300	133.0x128.8	29.5x43.9	27.7x27.7	2.85	748x724
			147.2x141.4	31.2x40.2	28.2x27.9	2.85	826x794

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TABLE XXVI. EFFECT OF HEATING ON PHYSICAL PROPERTIES OF UNCOATED FABRICS

Fabric	Time Mins.	Temp. °F.	Tensile Strength Lbs/In.	Elongation %	Tear Strength Lbs	Weight Oz/Sq.Yd	Strength Weight Ratio
Dacron							
15018	--	--	182.2x192.6	25.3x23.1	74.0x68.2	5.75	507x536
Greige	30	300	221.8x236.6	51.9x39.5	121.0x122.4	7.95	446x477
15018	--	--	208.4x220.2	34.8x32.1	91.4x76.4	6.5	513x542
Scoured	30	300	224.8x232.6	46.3x34.6	109.0x100.4	7.45	482x500
15018	--	--	226.4x236.4	58.6x48.0	128.0x118.4	8.05	450x470
Scoured and Heat Set	30	300	230.2x236.8	52.9x45.5	142.0x126.8	8.15	453x466
Dadron							
15020	--	--	85.6x91.0	14.2x20.4	28.1x32.2	2.60	527x560
Greige	15	300	105.8x107.6	37.6x42.0	37.8x47.5	3.60	470x478
	30	300	108.8x106.0	35.3x40.1	38.7x48.0	3.60	484x471
	60	300	108.0x109.8	37.6x40.0	38.3x46.1	3.65	474x481
	30	350	111.8x114.8	42.6x46.1	39.2x44.1	3.85	465x477
15020	--	--	101.2x92.8	24.9x28.4	35.4x35.3	2.95	549x505
Scoured	15	300	109.8x107.0	34.1x40.2	43.8x40.5	3.60	489x475
	30	300	108.6x100.4	34.0x40.2	46.6x39.4	3.50	497x460
	60	300	112.7x106.4	35.1x41.1	39.5x35.7	3.50	515x387
	30	360	115.8x112.6	38.0x45.6	37.7x35.7	3.75	495x480
15020	--	--	121.6x107.6	36.6x49.0	43.5x44.7	3.75	519x459
Scoured	15	300	115.0x112.0	36.7x48.1	45.2x41.4	3.75	492x478
and	30	300	118.7x104.6	39.8x46.3	40.9x38.4	3.80	500x441
Heat Set	60	300	119.5x111.4	37.3x49.5	41.0x38.3	3.75	509x475
	30	350	119.8x110.6	36.8x50.9	32.3x33.4	3.80	505x467
Dacron							
15023	--	--	187.0x189.8	13.1x15.0	65.1x66.9	3.85	778x790
Greige	15	300	214.2x217.6	40.4x39.8	88.9x102.0	5.40	635x645
	30	300	217.4x220.6	40.0x40.0	91.0x99.6	5.45	638x647
	60	300	214.8x215.0	40.5x42.0	91.4x92.1	5.60	614x615
	30	350	222.2x228.0	50.9x50.3	93.5x102.1	6.05	588x603
15023	--	--	206.6x204.2	21.1x24.8	74.5x73.3	4.20	787x779
Scoured	15	300	207.2x207.6	29.6x32.8	77.5x79.8	4.80	690x693
	30	300	210.6x212.4	32.0x32.9	75.2x80.4	4.70	717x723

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TABLE XXVI. EFFECT OF HEATING ON PHYSICAL PROPERTIES OF UNCOATED FABRICS *SHEET 2

Fabric	Time Mins	Temp. °F.	Tensile Strength Lbs/In.	Elongation %	Tear Strength Lbs	Weight Oz/SqYd	Strength Weight Ratio
15023	60	300	210.4x214.0	31.9x33.6	76.1x78.6	4.90	688x700
Scoured	30	350	217.0x220.0	41.3x43.0	74.4x78.6	5.45	637x646
15023	--	--	217.8x215.8	35.9x43.5	88.5x94.1	5.30	658x652
Scoured	15	300	221.0x213.8	34.8x44.9	93.0x94.4	5.45	649x625
and	30	300	226.0x219.8	37.3x46.8	87.6x85.4	5.45	664x645
Heat Set	60	300	224.2x218.2	37.1x46.8	83.2x86.5	5.45	658x640
	30	350	225.4x221.8	41.0x50.2	73.5x78.1	5.70	634x623

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TABLE XXVII. EFFECT OF HEAT ON SPECIAL HEAT SET FABRICS

Fabric	Tensile Strength Lbs/In.	Elongation, % 20% Load	Elongation, % Ultimate	Tear Strength Lbs	Oz/Sq.Yd	Strength Weight Ratio
Nylon 3142G	187x187	5.5x6.3	24.4x26.1	81x82	3.55	842x842
Heated, 30 min 300°F.	181x201	4.6x5.7	21.8x24.1	77x80	3.55	815x905
Nylon 3143G	130x131	4.3x5.7	19.3x18.6	24.5x18.5	2.50	832x838
Heated 30 min 300°F.	129x130	5.7x5.0	21.0x21.0	24.6x19.7	2.55	811x815
Dacron 15020G	109x108	0.7x1.0	26.4x31.1	40.0x40.6	2.90	600x595
Heated 30 min 300°F.	107x109	0.7x1.0	29.5x30.7	37.0x36.8	3.00	571x531
Dacron 15023G	200x205	3.3x2.7	28.5x25.6	77x84	4.45	720x738
Heated 30 min 300°F.	205x209	3.3x3.0	26.3x27.8	72x78	4.35	720x735

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FIGURE 79
EFFECT OF TEMPERATURE
ON STRENGTH OF FABRICS
TIME OF HEATING 30 MINS.

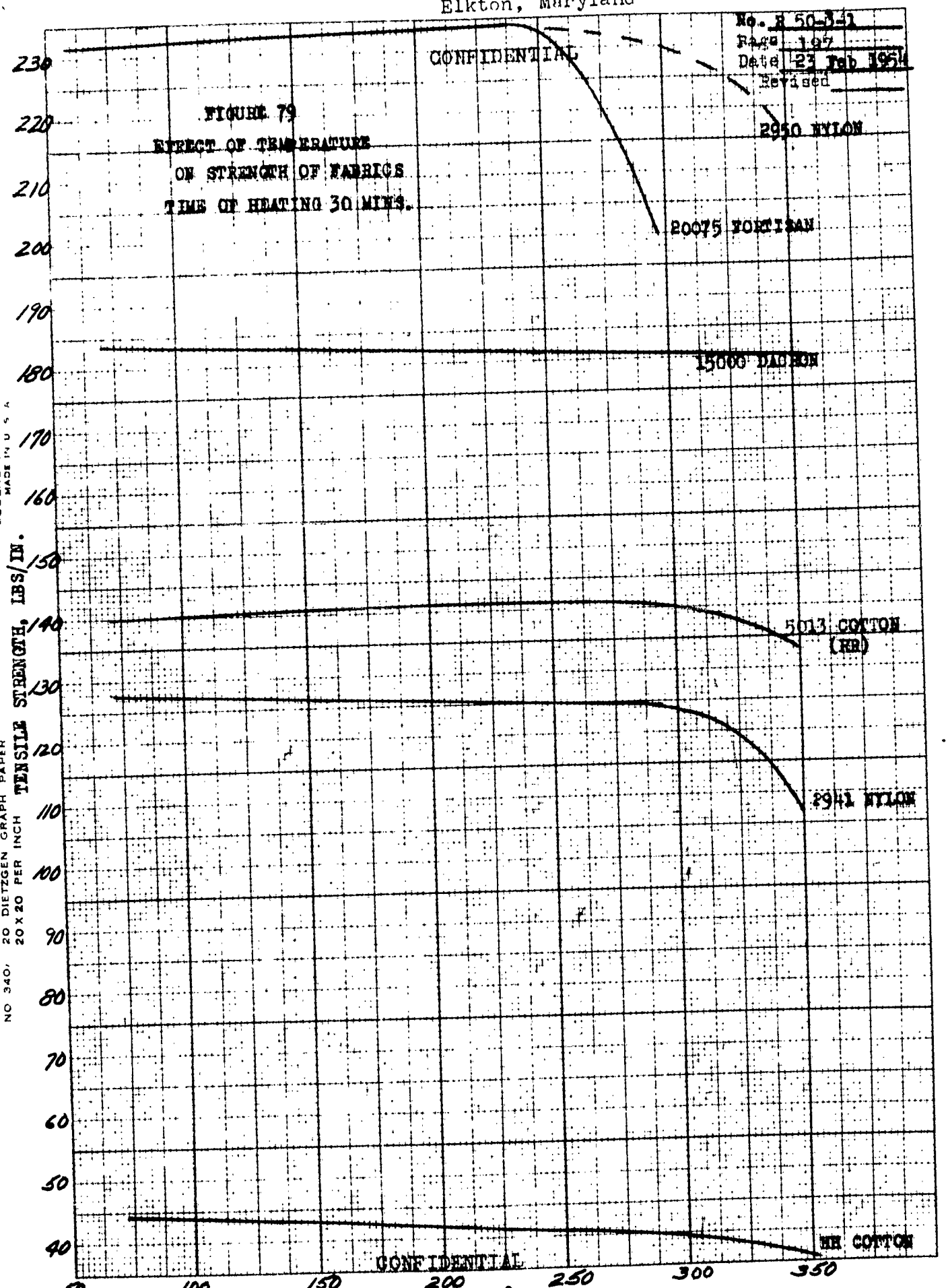

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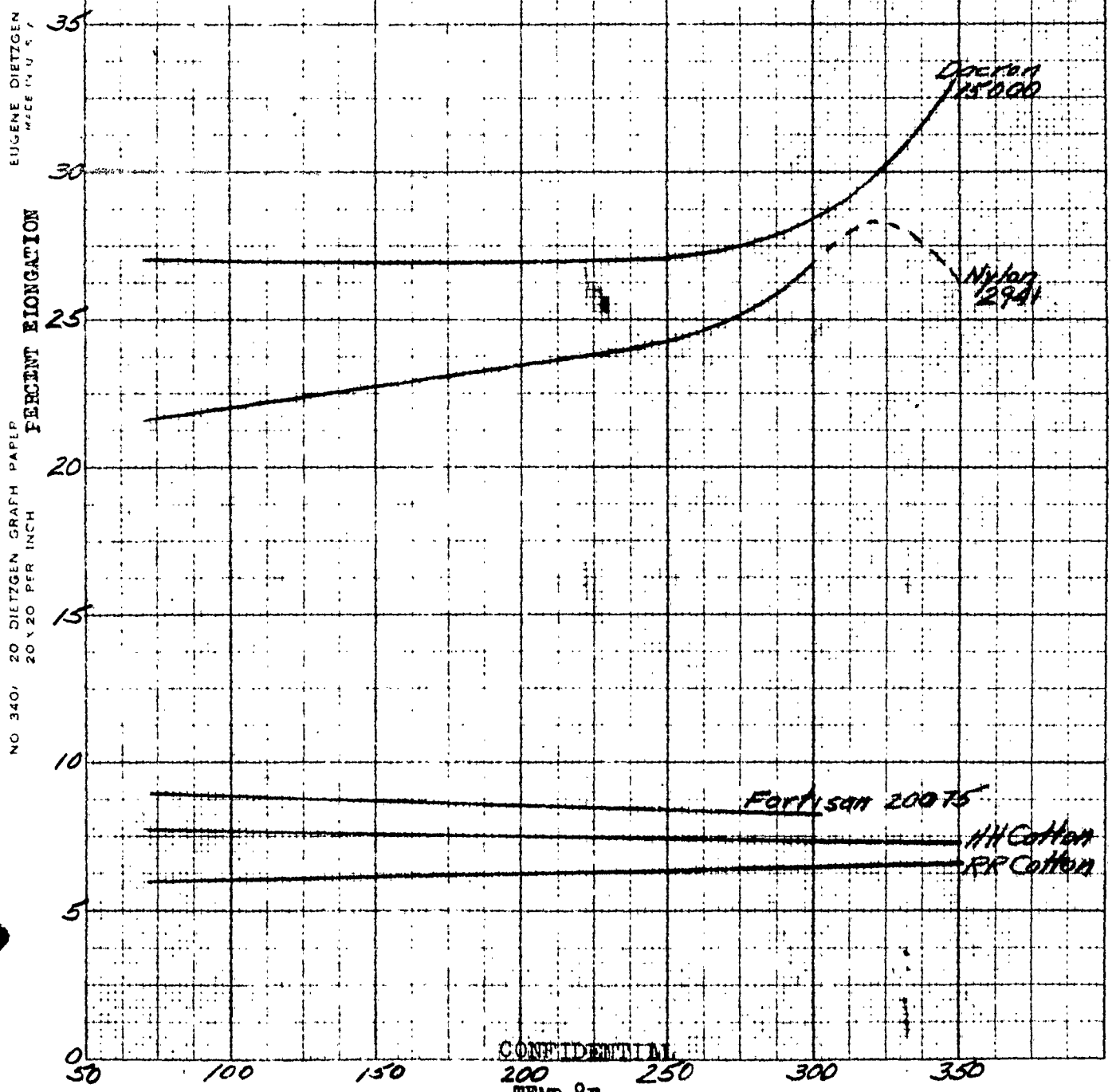
FIGURE 50
EFFECT OF TEMPERATURE
ON ULTIMATE ELONGATION
OF FABRICS
TIME OF HEATING 30 MINS.



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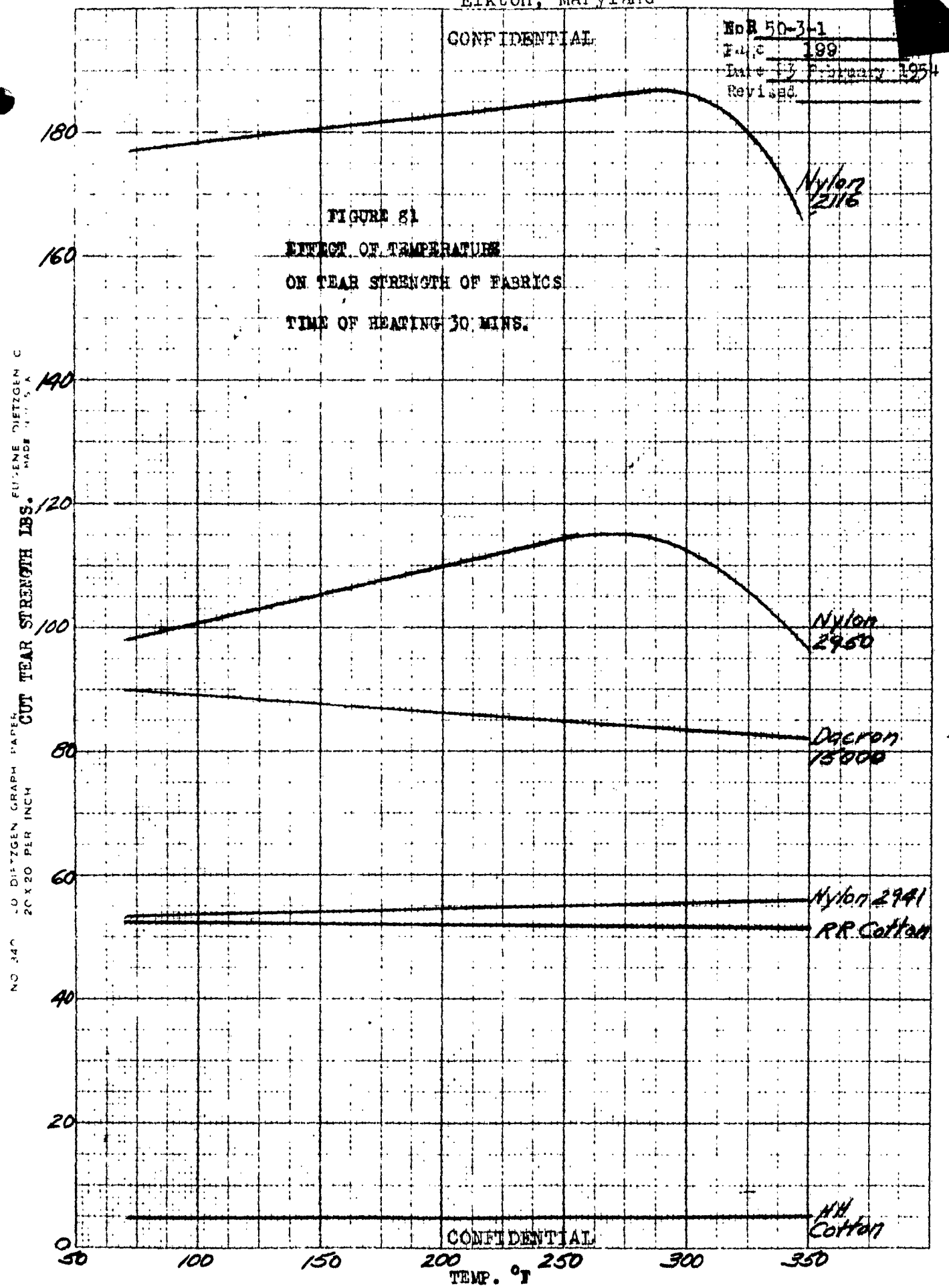

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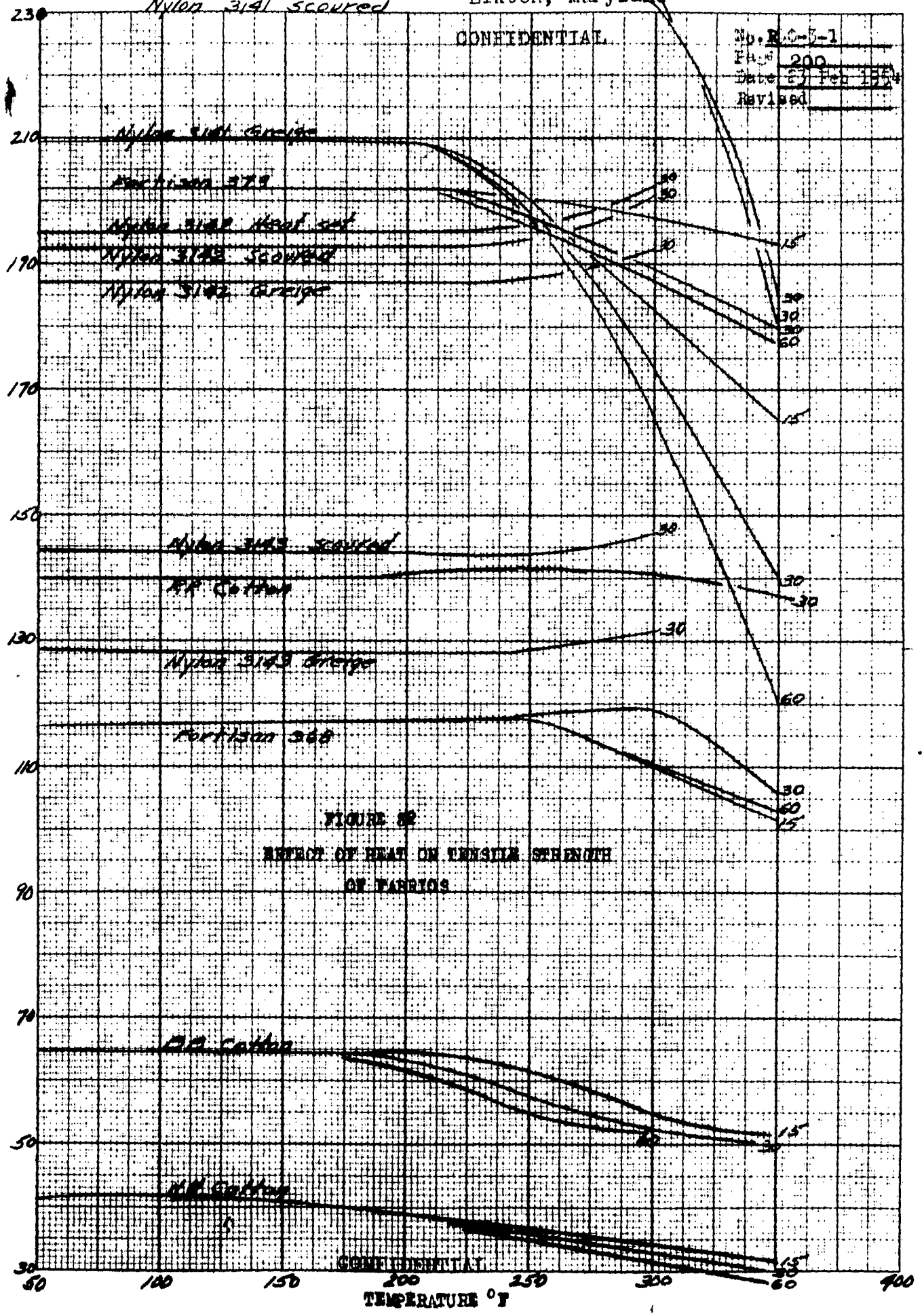

FIGURE 82

EFFECT OF HEAT ON TENSILE STRENGTH OF FABRICS

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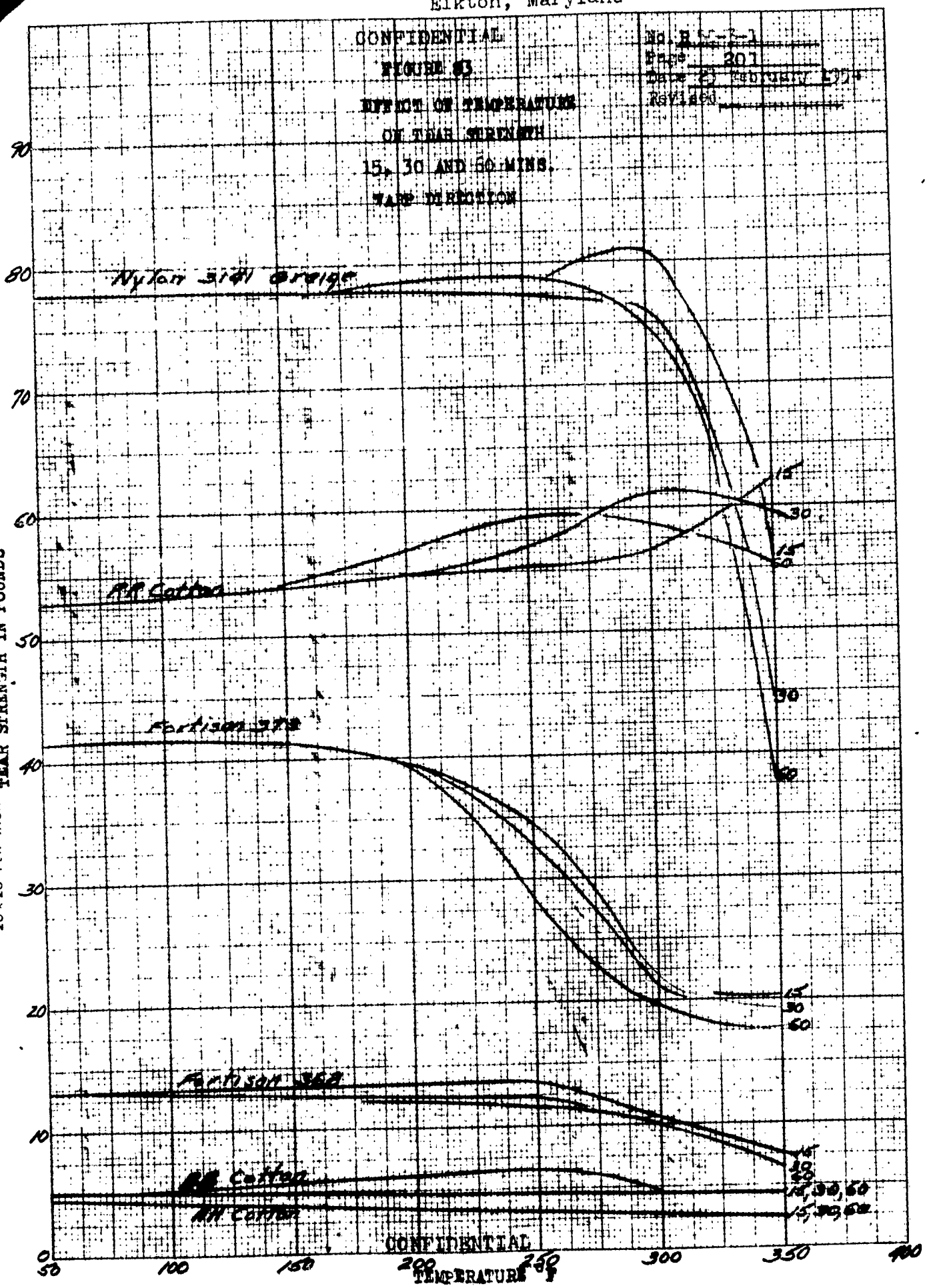
FIGURE 83
EFFECT OF TEMPERATURE
ON TEAR STRENGTH
15, 30 AND 60 MINS.
WARP DIRECTION



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5.3.2 Coated Fabrics

5.3.2.1 Effect of Coating

There is the possibility that coating of a fabric will improve or detract from its mechanical behavior. A few preliminary experiments were carried out at the beginning of a complete study.

The coating composition, rather arbitrarily chosen, had the following formula:

Neoprene WRT	100.0
Neozone A	2.0
Stearic Acid	0.5
Light Calcined magnesia	4.0
Philblack A	29.0
Zinc oxide	5.0
	140.5

The components were milled on a two roll mill and then the mixture was dissolved in toluene to form a 25% solids solution. Before use, 0.5 parts of Permalux accelerator dissolved in methyl ethyl ketone was added.

The coating was applied by knife coating and by coating only on the top surface. Cast coating was carried out by casting a Neoprene film on glass using a spreader of definite clearance.

Some of the solvent was allowed to evaporate and then the fabric was gently forced into the film. After drying, the coated fabric was stripped from

the glass and cured. Curing in all cases was for 30 minutes at 300°F.

The results of the coating experiments are summarized in Table XXVIII.

It can be seen that coating increases the tensile strength of the cotton fabric, but has little or no effect on the nylon and Dacron fabrics.

The effect of coating on the complete load-elongation curves are shown in Figures 84 to 86.

Tear strength decreases considerably after coating the cotton and Dacron fabrics, and slightly after coating the nylon fabric.

There appears to be little difference in the effect on physical properties of knife coating or cast coating. The outstanding advantage of cast coating appears to be in the case of obtaining coated fabrics free of pinholes in one operation. This may allow the use of thinner films and therefore less coating weight.

Coating of fabrics was carried out in two different ways in order to determine the effect of degree of penetration of the coating into the fabric. Knife coating resulted in a high degree

of penetration. A low degree of penetration was achieved by the equivalent of laminating a film of Neoprene to the fabric. These methods of coating are designated P and S respectively in the tables and figures.

The original coating work was done with Neoprene WRT in toluene solution. A shift was made to Neoprene W because of its better film properties. However, it is low in tack, making it difficult to obtain good adhesion between plies. Following the recommendation of E. I. DuPont de Nemours & Co., Neoprene GRT was used to improve ply adhesion. It is likely that both type GRT and type W will be used in the final product.

Neoprene W was used in the study of the effect of coating weight on physical properties. The following formula was prepared by milling the Neoprene on a cold mill for ten minutes, adding the other ingredients and milling for an additional ten minutes.

Neoprene W	100.0
Neozone A	2.0
Stearic Acid	0.5
Lt. calcined magnesia	4.0
Philblack A	29.0
Zinc Oxide	5.0

This mixture was dissolved in 421.5 parts of toluene to produce a 25% solids solution.

Work was continued on the effects of a Neoprene coating on physical properties of fabrics. Earlier results were erratic, so five duplicate samples were run in this series. The results are listed in Table XXIX. They check the results for cotton and nylon obtained in earlier data and establish the behavior of Fortisan. Zero points are for fabrics heated under curing conditions.

This study did not include scoured or heat-set nylons. Dacron fabrics had not been received at the time the work was done. This data will be obtained during the work on making plied fabrics.

Tensile strength of the cotton fabrics increases with increasing coating weight. This effect is greatest with RR cotton #368. Fortisan loses tensile strength with increased coating weight. Nylon (greige) increases slightly in strength and then does not change as the amount of coating is increased.

The curves of coating weight versus tensile strength are plotted in Figure 87.

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Strength-weight ratios of the coated fabrics are given in Table XXIX and plotted in Figure 98. The main point to note is that the ratio for BR cotton changes less with coating weight than for the Fortisan or nylon fabrics. The big advantage in strength-weight ratio of these fabrics is reduced in the form in which they are to be used. Comparisons should not be made at the same weight of coating because this amount differs in the plied fabrics. For example, the Fortisan envelope fabric contains less Neoprene than the cotton envelope fabric. The difference in strength-weight ratios, therefore, is larger. The final basis for comparison must be the cylinder burst strength-weight ratio of the plied fabrics. These are 177 and 294 for the cotton and Fortisan envelope fabrics respectively. (Specification strengths were used in the calculation).

Tear strength of the fabrics is reduced by coating. However, BR cotton and HH cotton may become stronger. These two fabrics tear below the accurate range of the measuring instrument, so the change may not be significant. The results are shown in Figure 99.

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Creep tests of coated fabrics were continued, and the curves are shown in Figure 90. There are two surprising things about the curves. One is the change in level of the curves over a period of 10-20 days for all curves except Fortisan and nylon 2941. We have no explanation for this change. The other unexpected result is the lack of creep of coated nylon 2941. The curve for the uncoated sample is included in Figure 90. This shows no creep after about nine days under load. The curve for the coated sample is the same except that the total elongation is higher (8.2% and 11% respectively). Heat-set and scoured nylons all show continued creep. The coated sample which had been heated to cure the coating, therefore, would be expected to show creep. The coating would seem to be responsible for preventing this. However, the creep curves of greige nylon 2141 before and after heating show no change (see Figure 91).

Lack of creep makes greige nylon another possibility for an envelope material.

Some experiments were carried out on coating and plying greige Dacron type 5500 fabrics. The data is summarized in Table XXX. This combination is not satisfactory because of excessive curling and wrinkling due to shrinkage. The total weights

also are high. Use of a lower solids primer and surface coating gave much higher adhesion results. The total amount of Neoprene is higher also.

Scoured heat-set Dacron 15023 basket weave and scoured heat-set Dacron 15020 twill were coated and plied. The Dacron type 5300 twill had to be used because of 75 denier type 5100 is not available for making a twill. The test results on these fabrics are given in Table XXXI. The differences in permeability and adhesion seem to be due mainly to the use of different Neoprene compounds. The better results were obtained with Neoprene compounds which were degraded least during milling.

If a Dacron type 5100 twill were available, or if a nylon twill can be used, the total weight could be reduced by about 1 oz/sq. yd.

The variable results and loss of permeability after Rotoflexing in samples made by placing fabric into partially dried Neoprene films showed the need for a better method. One method which is promising is to coat the Neoprene film on a smooth surface and dry it. Fabric is placed on this film and coated from the back with an MDI -- Neoprene cement. When dry, the Neoprene film combined with fabric can be stripped from the surface. A series

of laboratory samples was prepared in this manner from scoured, heat-set Dacron 15023 and Dacron 15020. The results are shown in Table XXXII.

The drying cycle of the film before applying the fabric is important. Air drying overnight causes loss of tack so the film had to be wet with toluene. Drying for 2 hours at room temperature gives good adhesion results, but the permeability after rotoflexing is very poor. Drying at 300°F. for one minute gives the best results.

The change in tensile strength observed after Rotoflexing is a measure of fatigue of the base fabric. Nylon is the best meterial as would be expected. The change in permeability is not due to breakdown of the Neoprene. It appears to be due to a change in the amount of "fabric help". Fabric help may be related to adhesion. The difference in permeability of an unsupported Neoprene film and the same weight per sq. yd. of Neoprene coated on a fabric is due to "fabric help".

The decrease in initial permeability due to the fabric depends upon how the film is applied. If the film is all on the surface of the fabric, permeability is that of a free Neoprene film. It does not change after Rotoflexing. If the fabric is impregnated, permeability is less than that of a

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free film of the same weight. Fibers occupy some of the volume, so a given weight of Neoprene forms a thicker coating. If the film breaks away from the fabric because of low adhesion, thick spots form and permeability increases.

The main advantage of fabric help is a saving in weight of Neoprene to obtain a given initial permeability. Therefore, maximum fabric help is desirable. For Dacron fabrics it appears that the weight of Neoprene between plies should be 5 - 6 oz/sq. yd. to attain and maintain a permeability of 3 $L/M^2/24$ hrs. or less. This is shown in Figure 92. An attempt was made to lower the required quantity of neoprene between plies and still maintain the desired permeability.

As work progressed, it was found that it was possible to reduce the amount of neoprene between plies to 3 to 3.5 oz. sq. yd.

The first series of experiments was run to determine effects of a variety of methods of making dry film laminates.

The results led to the conclusion that a suitable fabric can be made with a film weight between plies of 3 to 3.5 oz/sq. yd.

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These conditions for coating and plying were applied to the preparation of a series of laboratory samples made with greige heat-set Dacron. The composition and properties of these samples are summarized in Table XXXIII. The results show that it is possible to prepare a Dacron envelope fabric having a weight of 14.0 ± 0.5 oz/sq. yd. None of the samples has an aluminum coat.

In this table, and others following, the backs of the basket weave and twill fabrics become the outside surfaces of the plied fabric. The faces are plied together.

The fabric help ratio is the ratio of permeabilities of the plied fabric to that of a free film of Neoprene having the same weight per square yard as the Neoprene in the fabric.

All Rotoflex tests are carried out at 200 cycles per minute each of four directions, with a load of 3000 grams.

Another series of laboratory samples was prepared with greige heat-set nylon. The composition and properties of those samples are summarized in Table XXXIV. The results show that it is possible to prepare a nylon envelope fabric having a weight of 13.0 ± 0.5 oz./sq. yd. Again none of the samples has an aluminum coat.

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A comparison of the properties of the Nylon and Dacron plied fabrics is of interest. The nylon fabric is about one ounce per square yard lighter in weight. The average strength of the samples in the tables is lower for nylon (200.3 lbs/in) than for Dacron (236.2 lbs/inch). The average strength-weight ratios are about the same, 255 and 249. Elongation at 20% of breaking load is lower for Dacron (2.1 % av.) than for nylon (3.5% av.). The percent decrease in strengths after 5 minutes of Rotoflexing is about the same for these nylon and Dacron fabrics. This was not the case for the regular heat-set fabrics described in previous pages, where the nylon material has better fatigue resistance than the Dacron fabric.

The next procedure was to transfer the laboratory method to plant equipment. A series of seventeen 30 inch by 8 inch Dacron samples prepared in the laboratory was laminated in the plant. Adhesions did not change much with plying conditions. Initial permeability decreased slightly with increasing temperature. This is shown in Figure 93. Permeability did not change much with pressure. Differences did appear after Rotoflexing, depending upon the amount of Neoprene between plies.

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TABLE XXVIII. EFFECT OF COATING ON PHYSICAL PROPERTIES OF FABRICS

Fabric No.	Coating Method	Number of Coats	Coating Wt. oz/sq.yd	Strip Tensile lbs	Elongation %	Cut Tear lbs
5013	knife	0	0.0	136	4.6	52.6
Cotton		1	0.6	139	5.0	48.3
		3	1.9	165	5.0	31.2
		5	2.6	144	5.0	24.3
		8	3.5	166	5.3	22.2
	cast	1	3.6	148	5.6	19.4
2583/S	knife	0	0.0	150	39	55.2
Ripstop		1	3.6	144	34	46.4
Nylon		3	4.4	151	34	40.5
		5	5.1	154	31	41.1
		8	5.9	157	33	40.9
	cast	1	5.5	143	46	47.0
15008	knife	0	0.0	129	18	51.4
Dacron		8	2.6	132	27	27.2
	cast	1	2.9	126	28	24.2

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TABLE XXIX. EFFECT OF COATING WEIGHT ON PROPERTIES OF FABRICS

Fabric	Coating Weight Oz/Sq.Yd	Tensile Strength Lbs/In.	Strength Weight Ratio	Elongation %	Tear Strength Lbs.
RR Cotton	0	140	435	4.8	61.2
	0.83	142	380	7.5	51
	1.55	154	367	6.9	29
	2.70	153	312	5.3	21
	3.65	167	303	5.3	21
	4.65	157	256	5.7	20
BB Cotton	0	52.0	368	10.6	4.2
	0.25	55.7	293	10.8	7.2
	0.45	63.5	313	13.0	7.2
	1.25	53.8	212	10.5	7.9
	1.70	58.3	207	12.5	7.9
	2.95	67.2	187	12.8	7.6
HH Cotton	0	34.3	281	5.4	2.8
	0.10	38.6	301	7.4	4.5
	0.52	39.4	255	7.7	4.9
	1.16	39.3	202	6.6	5.0
	1.40	43.8	209	6.7	5.1
	2.41	37.5	138	6.9	5.3
Fortisan 368	0	119.2	846	6.8	10.0
	0.19	107	716	7.5	10.9
	0.45	115	694	7.0	9.4
	0.74	99	539	5.7	8.4
	1.31	105	479	6.0	7.8
	1.47	105	458	6.1	7.4
Fortisan 373	0	186.4	897	6.2	21.9
	0.14	181	773	12.0 (?)	24.4
	0.59	185	707	7.3	21.5
	0.77	190	695	7.4	19.6
	1.35	199	643	7.3	17.7
	2.11	174	487	6.7	17.5
Nylon 3142 Greige	0	192.4	905	25.7	83.3
	0.52	189	772	26.8	61
	1.44	200	662	27.8	51
	2.48	201	547	27.7	43

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TABLE XXIX. EFFECT OF COATING WEIGHT ON PROPERTIES OF FABRICS(cont)

Fabric	Coating Weight Oz/Sq.Yd	Tensile Strength Lbs/In.	Strength Weight Ratio	Elongation %	Tear Strength Lbs.
Nylon 3142	3.19	200	486	26.9	44
Greige	4.44	202	412	26.3	43
Nylon 3143	0	131.8	840	24.2	19.0
Greige	0.26	138	815	26.3	15.5
	0.82	140	684	24.6	14.7
	1.25	131	567	22.0	15.0
	1.94	125	456	20.3	15.1
	3.05	134	396	20.1	

TABLE XXX. COMPOSITION AND PROPERTIES OF PLIED GREIGE

DACRON 15018 AND 15020

Wt. of Neoprene Basket		Oz/Sq.Yd Twill			Tensile Strength	Elongation		Permeability	Adhesion	Total Wt. Cured Fabric
Back	Face	Back	Face	Total	Lbs/In.	Ult.	20%Load	$L/M^2/24$ hrs.	Lb/Ins.	Oz/Sq.Yd.
0.7	2.12	0.80	2.24	5.96	287	54	4.0	1.3	3.6	20.1
1.25	1.05	2.00	0.95	5.25	278	73.7	12.0	15.5	3.5	19.2
0.55	1.40	1.05	2.25	5.25	262	62.7	10.7	200	3.8	18.55
0.45	2.50	0.40	3.00	6.35	276F	50.7F	4.0F	1.3	4.7	21.45
0.55	1.65	0.25	2.65	5.10	265	53.3	7.0	9.6	2.5	19.25
0.82	2.40	1.33	0.65	5.20	300 (over)	57.7	6.7	2.4	2.3	18.95
0.95	2.65	1.45	2.10	7.15	296	60.0	9.0	--*	10.2	20.7
0.85	2.45	1.30	1.95	6.55	283	57.3	9.3	--*	11.3	20.4

* no reading taken

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TABLE XXXI. COMPOSITION AND PROPERTIES OF PLIED SCOURED, HEAT-SET DACRON 15023 AND DACRON 15020

Wt. of Neoprene Basket Back	Face	Oz/Sq.Yd. Twill Back	Face	Total	Tensile Strength Lbs/In.	Elongation % Ult.	20% Load	Permeability $L/M^2/24$ hrs.	Adhesion Lbs/In.	Total Wt. Cured Fabric, Oz/Sq. Yd.
0.90	1.95	0.85	1.50	5.15	262	39.3	6.0	38.0	6.1	14.4
0.75	1.85	0.90	1.70	5.20	252	35.7	4.0	76.0	3.8	14.45
1.10	1.70	0.78	2.32	6.02	262	35.7	5.0	32.0	4.5	15.27
0.95	2.20	0.90	1.85	5.90	245	40.0	4.3	88.0	6.2	15.15
0.75	3.65	0.70	2.00	7.10	259	42.0	3.3	53.6[1]	9.5	16.35
0.55	3.30	0.90	2.20	6.95	262	56.0	4.0	37.0[1]	12.2	16.20
0.70	1.70	1.00	2.60	6.00	266	39.0	6.0	1.6[2]	7.2	15.25
1.00	1.70	0.80	2.85	6.55	242	35.7	3.3	0.5[2]	8.6	15.75
1.25	1.30	0.85	1.90	5.30	slipped	---	---	0.9	3.3	14.55

1. experienced difficulty with spreading compound

2. different compound than used in note(1)

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TABLE XXXII. COMPOSITION AND PROPERTIES OF PLIED DACRON FABRICS

MADE BY THE DRY FILM METHOD

Wt. of Neoprene Between Plies Oz/Sq.Yd	Wt. of Plied Fabric Oz/Sq. Yd.	Tensile Strength Lbs/In.	% Elongation Ult.	% Elongation 20% Load	Adhesion Lbs/In	Permeability L/M^2/24 hrs. initial	Permeability L/M^2/24 hrs. Rotoflex[1]	Tensile after Rotoflex Lbs/In.
4.00 (a)	14.65	254	46.7	3.3	12.4	3.4	5.6(2)*	222
4.00 (a)	14.06	232	37.3	2.7	12.2	4.6	4.8(2)	206
3.26 (a)	14.31	233	34.7	2.7	2.5	6.4	--	--
4.94 (a)	16.82	258	43.0	4.0	2.8	2.8	2.6(2)	216
4.40 (a)	16.50	252	37.0	3.0	6.2	3.0	2.8(2)	229
4.72 (a)	16.67	252	--	--	3.5	2.4	3.4(4)	224
4.62 (a)	16.65	254	--	--	5.9	3.8	3.6(4)	224
2.65 (b)	14.65	257	36.7	3.3	8.5	7.6	120.0(2)	224
4.29 (b)	17.08	244	37.0	3.0	11.2	3.2	180.0(2)	238
3.10 (c)	15.0	256	40.7	3.0	6.8	5.2	9.1(2)	220
3.55 (c)	15.45	242	38.3	2.9	8.4	4.2	8.8(10)	209
4.17 (c)	16.05	267	38.3	3.0	7.5	4.0	4.5(10)	--
5.20 (c)	16.15	235	38.7	3.3	6.8	2.5	2.4(10)	207
5.18 (c)	16.67	253	40.0	3.3	13.0	2.8	3.3(10)	211
6.15 (c)	17.15	246	45.7	2.0	10.2	1.9	2.8(10)	216

(1) 3,000 gram load used on all samples
* time in minutes in each direction; 3000 gram load.
(a) films dried overnight and wet with toluene before applying fabric
(b) films dried for 2 hours at room temperature before applying fabric
(c) films dried at 300°F. for one minute before applying fabric

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TABLE XXXIII. COMPOSITION AND PROPERTIES OF PLIED GREIGE HEAT-SET DACRON FABRICS

Sample No. PDH_2	1L	2L	3L	4L*	5L/	6L/
Coating Wt.Oz/Sq.Yd.	5.95	6.98	5.46	6.73	6.53	6.94
Basket, Back	0.28	0.59	0.51	0.50	0.62	0.84
Face	0.52	0.45	0.36	0.50	0.38	0.63
Film	1.65	1.98	1.50	2.01	1.84	1.64
Twill, Back	0.58	0.56	0.62	0.44	0.63	0.63
Back Film	1.10	1.07	0.70	1.03	0.62	1.08
Face	0.32	0.38	0.27	0.45	0.60	0.43
Film	1.50	1.95	1.50	1.80	1.84	1.73
Total between plies	3.15	3.93	3.00	3.81	3.68	3.37
Total Wt. Plied Fabric Oz/Sq.Yd.	13.50	14.53	13.01	14.28	14.08	14.49
Tensile Strength Lbs/In.	221.2	221.6	217.4	216.0	-	214.7
% Elongation, 20% Load	2.6	1.4	1.9	2.5	-	1.8
Strength-Wt. Ratio	262	243	266	236	-	238
Tear Strength, Lbs.	122	-	-	125	-	111
Adhesion, Lbs/In.	5.4	12.5	6.3	11.3	0.0	12.3
Permeability, $L/M^2/24Hr$						
Initial	1.6	1.2	2.0	2.2	-	2.4
7 secs. Rotoflex	-	8.0	4.0	2.6	-	3.1
2 mins. Rotoflex	2.7	13.2	-	2.9	-	-
5 mins. Rotoflex	3.4	13.2	-	3.5	-	4.0
10 mins. Rotoflex	-	offscale	5.2	3.5	-	-
Tensile after Rotoflex Lbs/In.						
2 mins.	-	185	207	204	-	-
5 mins.	193.5	150	188	178	-	196
10 mins.	-	139	189	180	-	-
% Loss in Strength after 5 mins. Rotoflex	12.5	32.2	13.5	17.5	-	9.0
Fabric Help Ratio	2.84	3.23	2.37	1.74	-	1.63

* New unfilled Neoprene adhesive used.
/ Crepe rubber adhesive used.

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TABLE XXXIV. COMPOSITION AND PROPERTIES OF PLIED GREIGE HEAT-SET NYLON FABRICS

Sample No. PNH_2	1L	2L	3L*	4L*
Coating Wt., Oz/Sq.Yd.	5.75	6.70	7.45	6.25
Basket, Back	0.63	0.34	1.21	1.05
Face	0.65	0.70	0.82	0.48
Film	1.65	2.02	1.86	1.71
Twill, Back	0.35	0.54	0.42	0.38
Back Film	0.60	0.90	1.00	0.84
Face	0.28	0.59	0.36	0.35
Film	1.59	1.61	1.78	1.46
Total Between Plies	3.24	3.63	3.64	3.17
Total Wt. Plied Fabric Oz/Sq.Yd.	11.80	12.75	13.50	12.30
Tensile Strength, Lbs/In.	203.0	200.0	200.0	198.4
% Elongation, 20%Load	4.0	1.7	4.2	4.0
Strength-Wt. Ratio	275	251	237	258
Tear Strength, Lbs.	132.5	-	122	120
Adhesion, Lbs/In.	10.9	11.8	11.7	14.1
Permeability, $L/M^2/24$ hrs.				
Initial	2.0	1.2	1.6	0.9
7 secs. Rotoflex	-	-	2.0	1.1
2 mins. Rotoflex	5.6	2.4	5.6	1.7
5 mins. Rotoflex	40.0	3.3	16.2	2.4
10 mins. Rotoflex	-	30.0	-	-
Tensile After Rotoflex, Lbs/In.				
2 mins.	-	173	182	182
5 mins.	170	164	174	182
10 mins.	-	166	-	-
% Loss in Strength After				
5 mins. Rotoflex	16.5	18.0	13.0	8.2
Fabric Help Ratio	2.35	3.36	2.25	4.81

* New unfilled Neoprene adhesive used.

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FIGURE 54

EFFECT OF NEOPRENE WET COATING ON NYLON FABRIC

2583/S

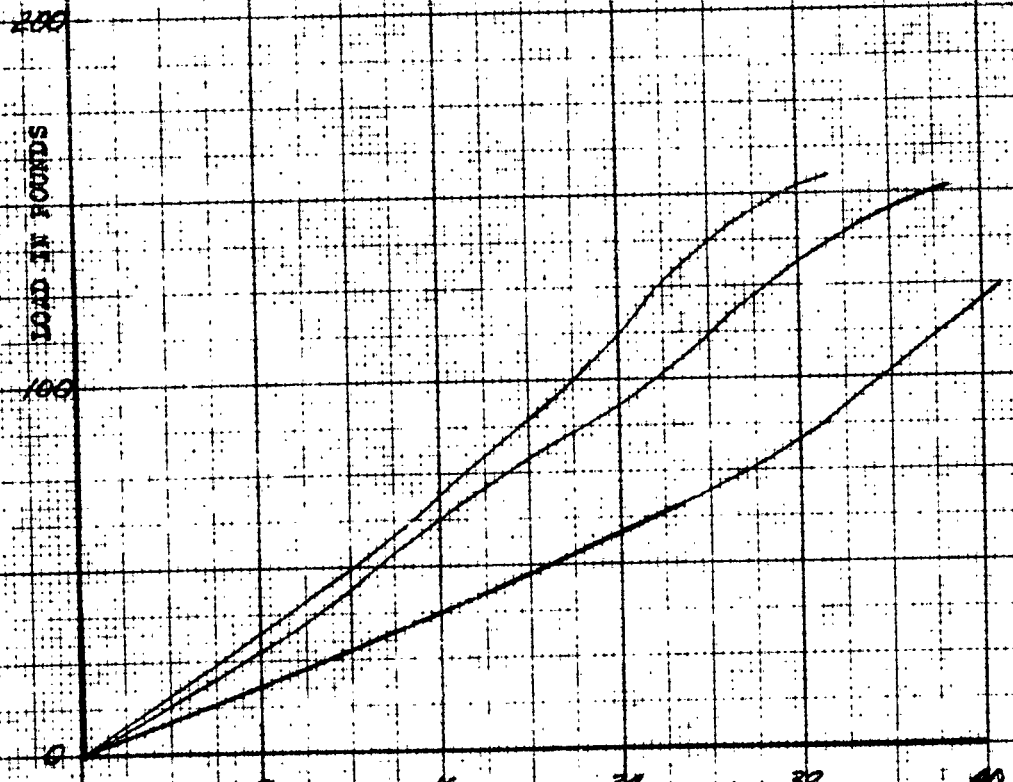

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FIGURE 65

EFFECT OF NEOPRENE WET COATING ON DACRON

FABRIC 1500[illegible]

COATING CURED 30 MINS. AT 300° F.

COATING WT. 2.[illegible] OZ PER SQ. YD.

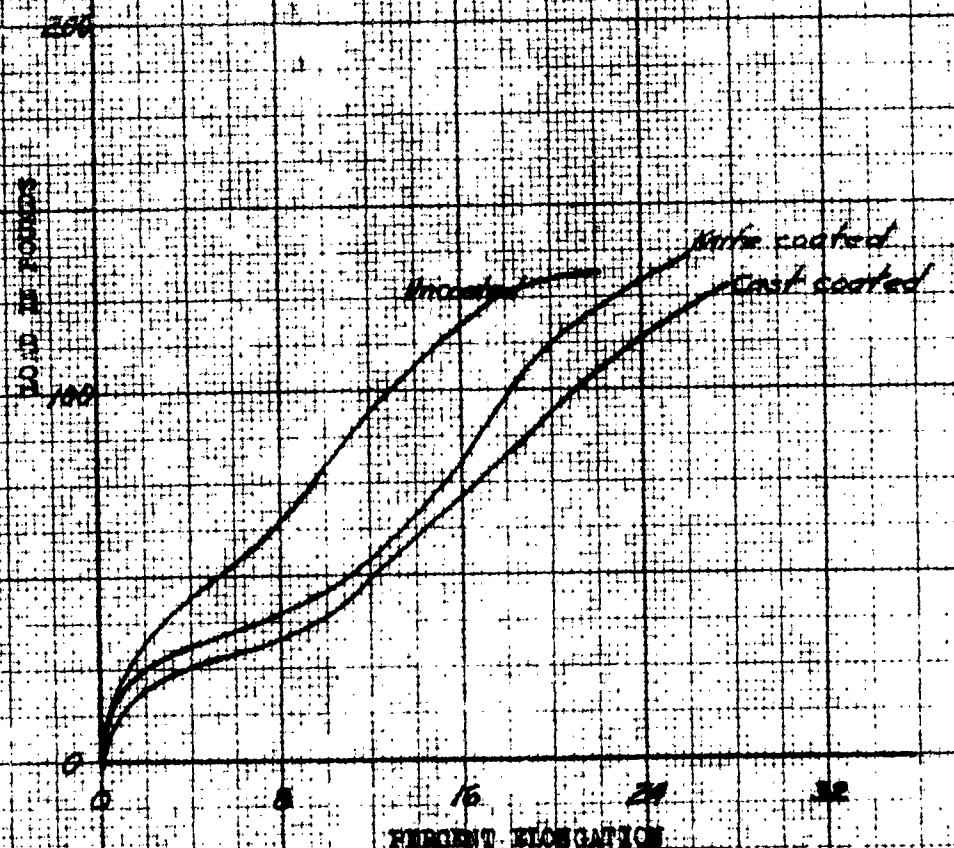

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FIGURE 86

EFFECT OF NEOPRENE WET COATING ON FABRIC 5013

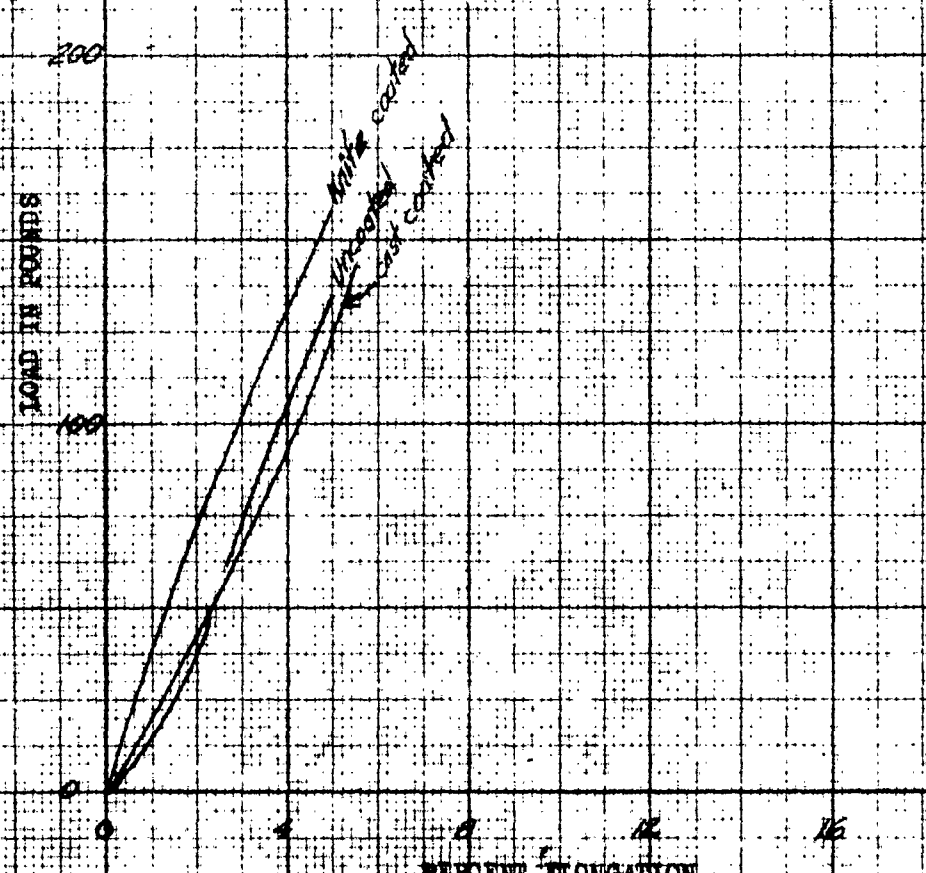

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FIGURE 87
EFFECT OF COATING WEIGHT ON TENSILE STRENGTH
CURED 30 MINS AT 300° F.
WARP DIRECTION

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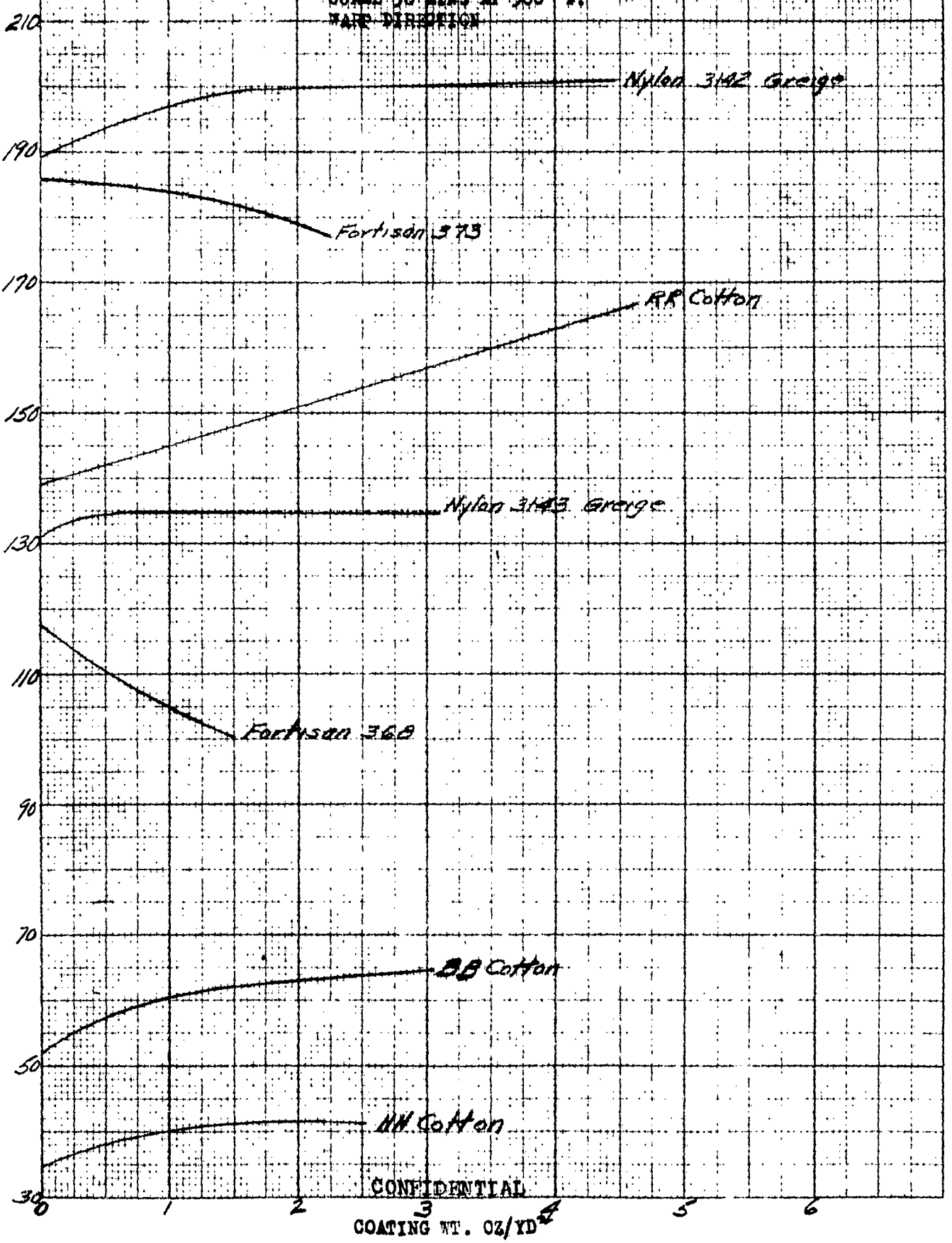

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FIGURE 55
CHANGE IN STRENGTH WEIGHT RATIO
WITH COATING WEIGHT

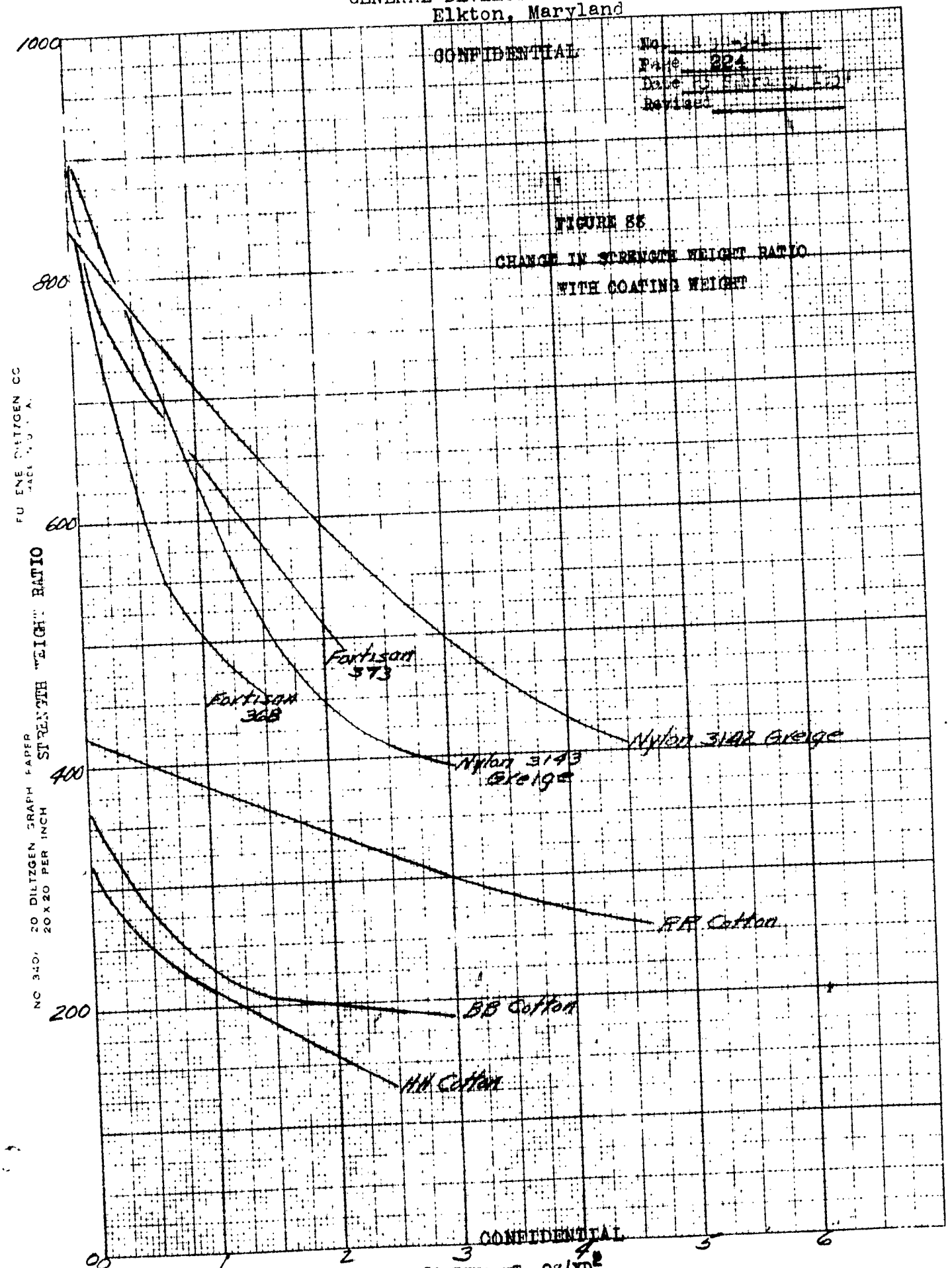

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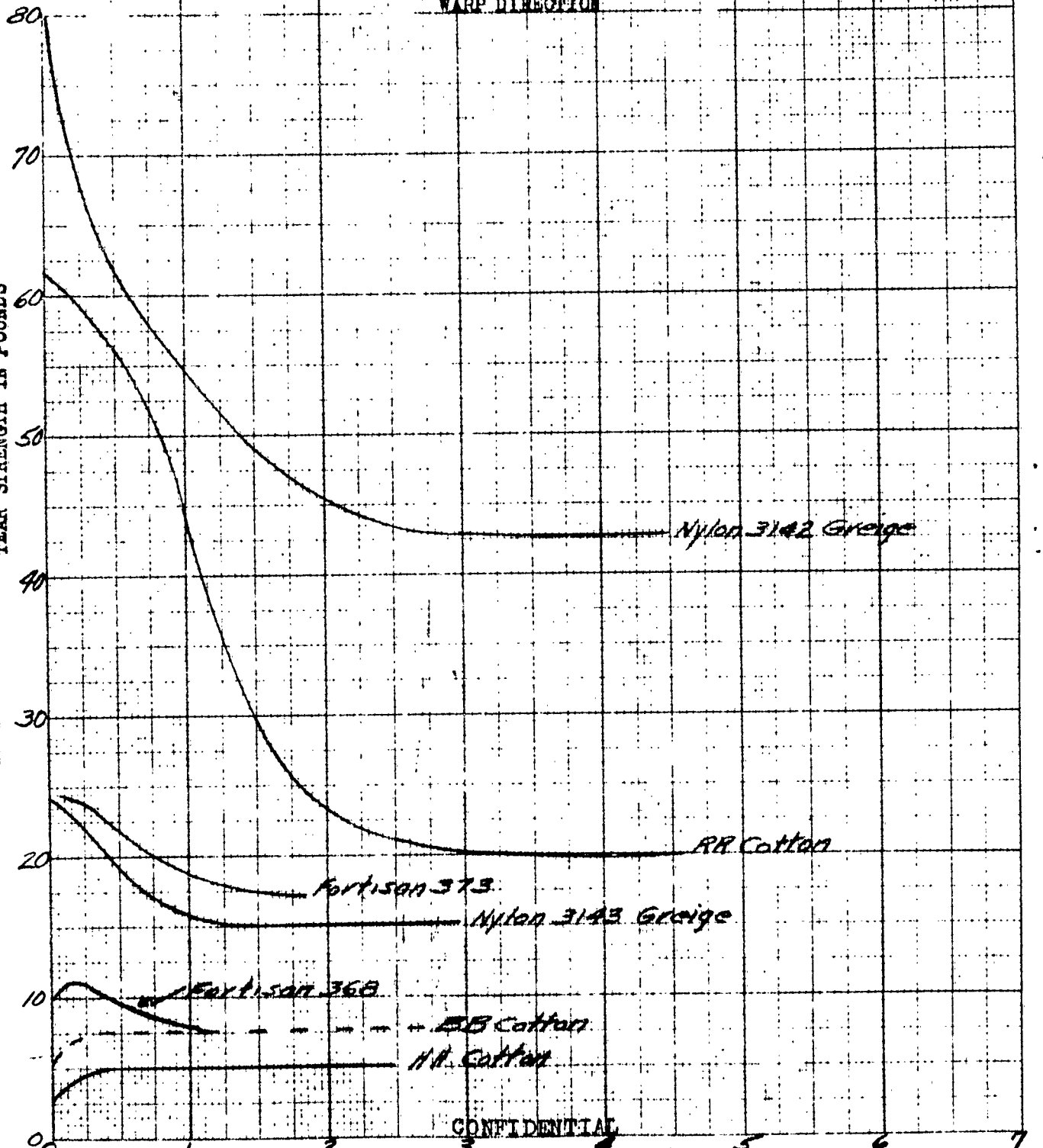
FIGURE 89

EFFECT OF COATING WEIGHT
ON TEAR STRENGTH
WARP DIRECTION



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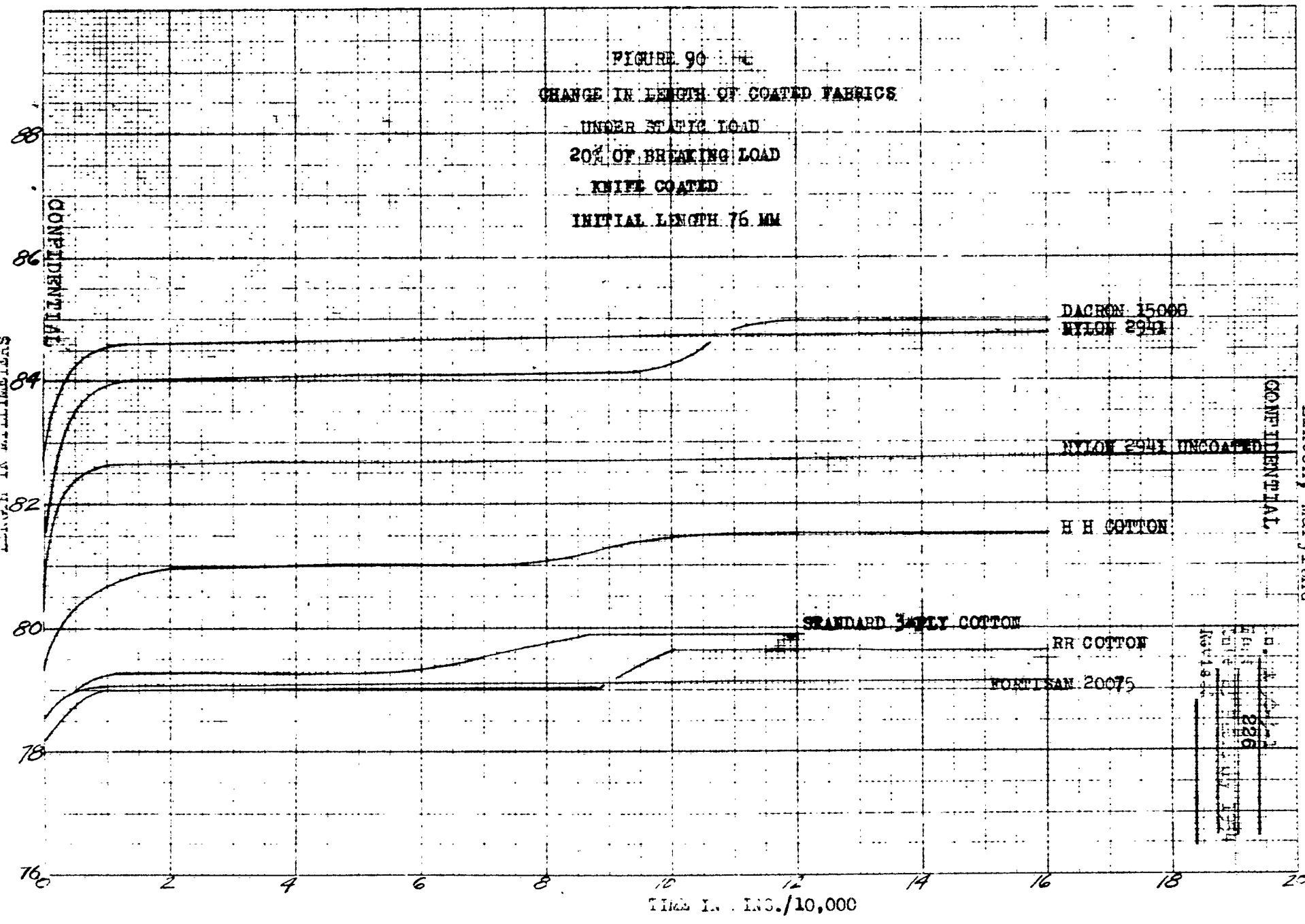

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FIGURE 91

EFFECT OF HEATING ON CREEP OF GRILON NYLON 3141

20% OF BREAKING LOAD

INITIAL LENGTH 76 MM

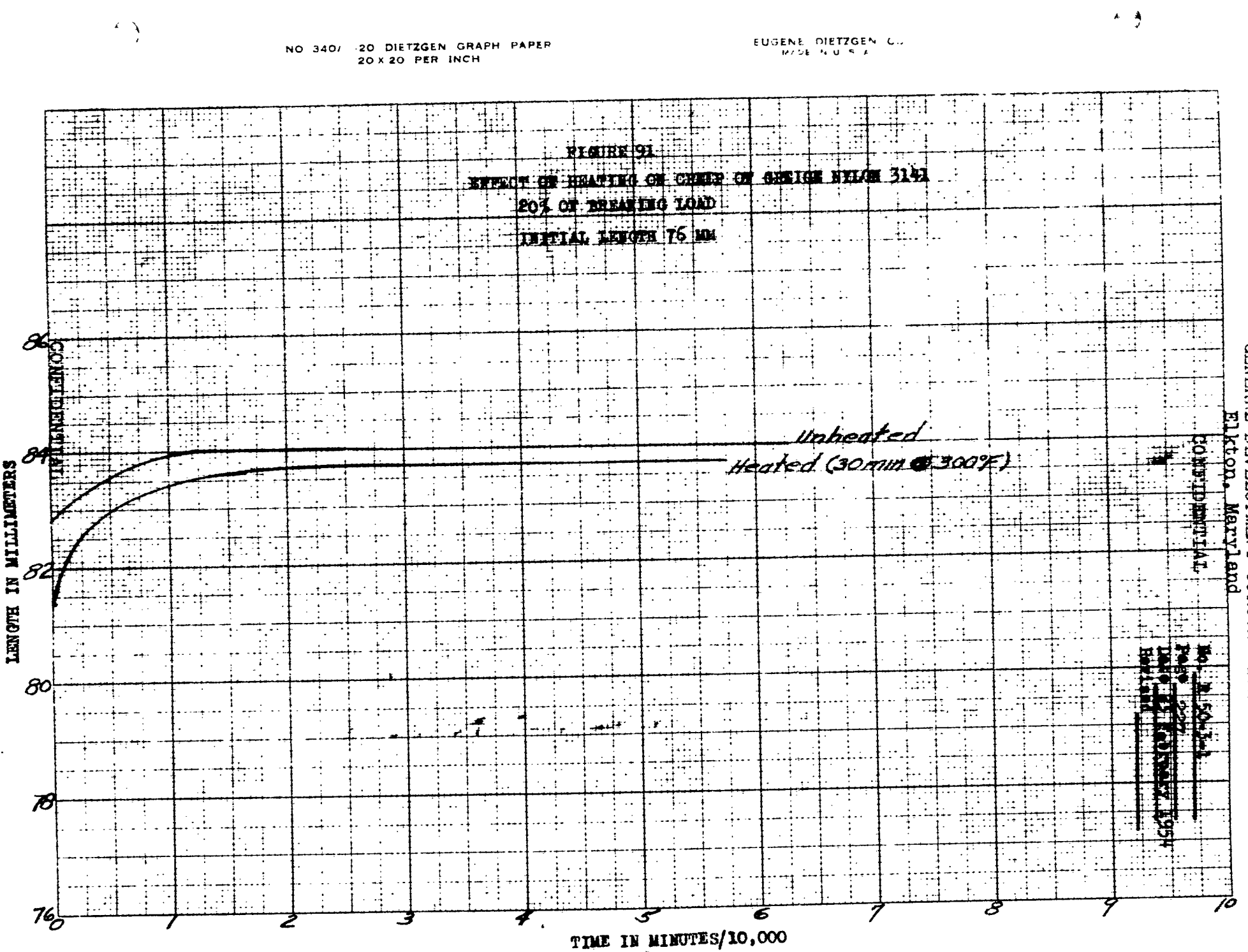

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FIGURE 92

EFFECT OF AMOUNT OF NEOPRENE BETWEEN PLIES UPON PERMEABILITY

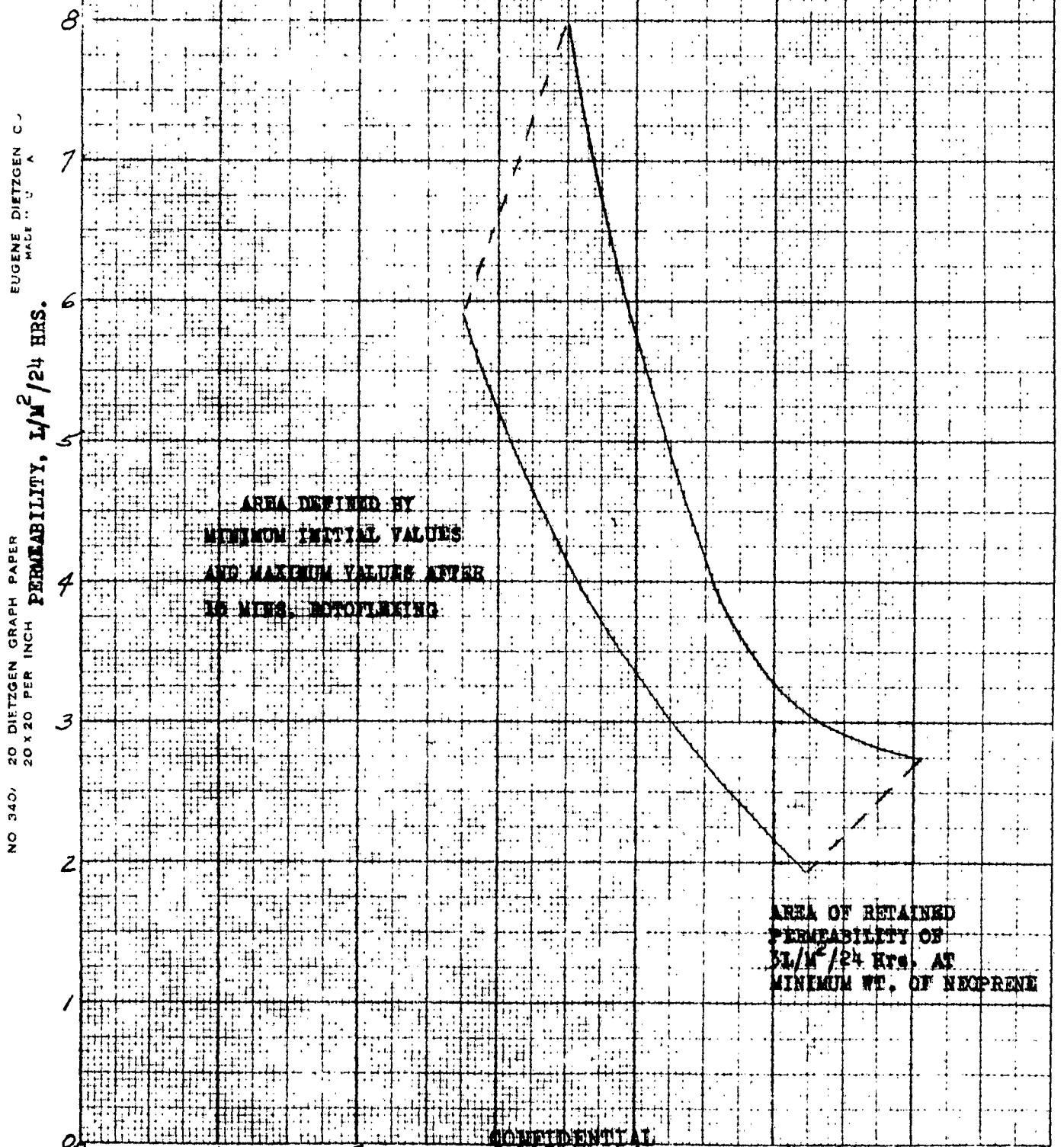

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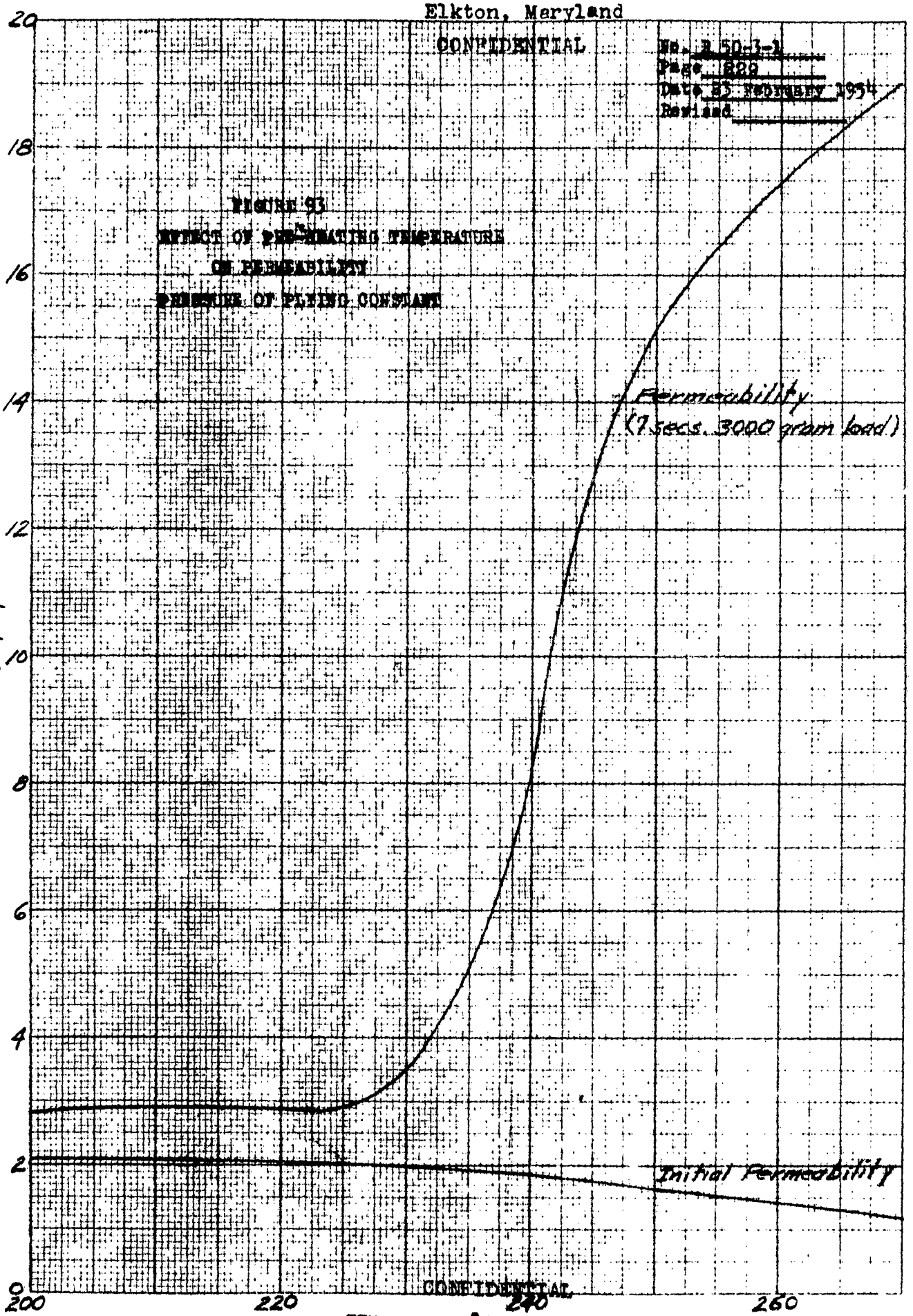
FIGURE 93
EFFECT OF PRE-HEATING TEMPERATURE
ON PERMEABILITY
PRESSURE OF FLUID CONSTANT



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5.3.2.2 Adhesion

Adhesion tests were carried out between RR cotton and 45° bias HH cotton, the construction used in the envelope fabric. Work will be done on adhesion between BB and HH fabrics, and then on a complete 3 ply fabric. It is expected that this study will result in a general understanding of the requirements for good adhesion which will be applicable to other fabrics.

Table XXXV summarizes the results on adhesion. In the first work with Neoprene W, adhesion did not approach or exceed 10 pounds (5 pounds per inch, the minimum specified) until the coating weight between plies was more than 5 ounces. This is much higher than the 3.3 ounces in the standard fabric.

A shift to Neoprene GRT, which has considerably more tack, showed that at least 3 ounces of coating was needed.

The amount of penetration of the coating into the fabric is a factor influencing adhesion. In some cases (sample 3) acceptable adhesion was obtained with a surface coat on each fabric. However, the degree of penetration is not known. It is low if tensile strength can be taken as a measure of penetration, since for this sample it is about the same as that of the uncoated fabric. Some samples have much higher tensile strengths, but poor adhesion.

There are two factors then, which effect adhesion

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for a given type of Neoprene. One is the total coating weight between plies, and the other is the degree of penetration. Good adhesion can be obtained with relatively little penetration if the coating is thick enough. If too much penetration occurs for the same coating weight, then there is too little coating on the surfaces between the plies.

Another related factor which affects adhesion is the distribution of the total coating weight between the two surfaces. In the series of samples 28 to 33, the total coating weight was kept roughly constant, but the distribution was varied. The results show that if there is too little coating on either fabric, the adhesion is low. This means that an amount of coating in excess of that which soaks into the fabric is necessary for adhesion. Knife coating the back of the RR fabric first helps to saturate the fabric and prevent excess penetration of the adhesive coats.

A study will be made of the effect on adhesion of formulation of the Neoprene coating to change its rheological properties and therefore its penetration into the fabric.

Further work on the adhesion of cotton fabrics proved that the results check the conclusions reached from preliminary work and that both sufficient Neoprene between plies and a controlled degree of penetration were necessary

for good adhesion at a minimum coating weight. The ratio of weights of coating on the two surfaces also is critical.

The results on RR-HH cotton plies made by knife coating are shown in the first part of this section.. Only a few samples had an adhesion of greater than five pounds per inch. This showed that considerable penetration took place and was difficult to control. In some cases enough Neoprene remained on the surface to give adhesion; in others it did not, even though the total weight of Neoprene was the same.

The degree of penetration depends partly upon viscosity of the coating compound. Two different compounds with different viscosities were tried. The results show that the higher viscosity (higher solids) material gives better adhesion for the same coating weight. These curves are plotted in Figure 94.

Another way to control penetration is by the method of coating. Application of the coating to the surface should give better results. Two samples were made in which the RR cotton was knife coated and the HH cotton surface coated. dhesion was improved as shown in Figure 94. Six samples were made with both fabrics surface coated. The back of the RR cotton was knife coated first. This method improved adhesion even more, as shown by the curve in Figure 94. This shows that surface coating with the

viscosity of Neoprene used at this time is the only method which gave adequate adhesion at a coating weight equal to, or less than that of the standard envelope fabric. The results are given in Table XXXVI. The HH fabric was plied at 45° to the RR fabric.

The ratio of HH coating weight to RR coating weight was kept within narrow limits. Review of earlier results showed that the ratio should be a minimum of about 0.4. No maximum was established. This minimum ratio must be used with the proper method of application and with enough Neoprene to obtain adequate adhesion.

Adhesion of HH cotton to BB cotton was studied separately. Results are given in Table XXXVII.

If all the coating is placed on one fabric, the adhesion is poor. It is greater if the coating is on the HH cotton. Again all surface coating gives better adhesion if the amount of coating is high enough. In sample 57 the amount is too low. In sample 59, there is enough Neoprene but the HH/BB coating ratio is too low. Not enough experiments were run to define the limits of coating weights and ratios.

Three ply cotton fabrics were prepared. The adhesion of plies following the same pattern as for two-ply fabrics. Table XXXVIII lists the results. The two samples which have acceptable adhesion between both plies also have the lowest total weight. However,

neither sample met permeability requirements, so more Neoprene must be used. A three-ply fabric which meets all specifications probably will have the same weight as the standard cotton envelope fabric. No attempt will be made to improve a cotton fabric. The purpose of working with cotton was to learn the factors which affect adhesion. This has been done and applied to plied nylon fabrics, as described.

The adhesion of two plies of nylon twill 3143 was studied using the surface coating method only. The results are summarized in Table XXXIX and show graphically in Figure 95. Adhesion of five pounds per inch or higher was obtained with coating weights of at least 4.8 ounces per square yard. The greige fabric has the lowest adhesion, and the scoured fabric has the highest adhesion.

Adhesion of surface coated nylon basket weave 3142 to knife coated nylon twill 3143 was studied. Figure 96 shows the effect of coating weight on adhesion. The heat set fabric has an adhesion of five pounds per inch or more at a lower coating weight than the scoured or greige fabrics.

The effect of the ratio of coating weight on the twill to coating weight on the basket weave also is shown. Adhesion is better at a ratio above 1.1 than at a ratio below 1.0. At the higher ratios, adhesion

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above five pounds per inch is attained at lower coating weights on the scoured and heat-set nylons than on the HH and RR cotton plies.

The data is summarized in Table XL.

Basket weave and twill combinations were made by using all knife coats. Heat-set fabrics have the highest adhesion. The data are listed in Table XLI, and plotted in Figure 97. A strict comparison with the combinations containing surface coated basket weave fabric is not possible because of difference in coating weight ratios. The all knife coated fabric adhesions fall between those of the two ratios of the other series.

Three-ply fabrics consisting of nylon 3142 and two plies of nylon 3143 were made. Composition and adhesion data is summarized in Table XLII. Adhesion closely follows adhesion of two-ply compositions, being dependent upon total weight of Neoprene and its distribution between the two surfaces.

All this work with nylon fabrics shows that it is difficult to obtain adhesion above specification limits unless a large amount of Neoprene is used. This increases the total weight of the fabric and lowers the strength-weight ratio. Means for improving adhesion at lower coating weights was sought. A recommended procedure is to use a prime coat of

Neoprene and an isocyanate such as p, p' methylene bis (phenyl isocyanate) (MDI). This was tried and found to improve adhesion considerably. Another known method is to use a prime coat consisting of resorcinol formaldehyde resin and rubber latex. This method is used on nylon tire cords. This treatment also improved adhesions. Results are summarized in Table XLIII for twill to twill adhesion and in Table XLIV for basket weave to twill adhesion. All fabrics are surface coated since this gives better results at lower weights.

The combination of resorcinol formaldehyde condensation product and Gentac latex (butadiene-vinyl pyridine copolymer) as a prime coat is not effective unless aged before application. The use of MDI-Neoprene is more effective in improving adhesion. The curves shown in Figure 98 better illustrate the improvements since comparison can be made at equal coating weights. Not enough points were determined for resorcinol formaldehyde to draw a curve.

TABLE XXXV. ADHESION BETWEEN NEOPRENE COATED RR AND HH COTTON FABRICS

Sample No.	Neoprene Type	RR Cotton Type Coating	RR Cotton Wt. Oz/Sq.Yd.	HH Cotton Type Coating	HH Cotton Wt. Oz/Sq.Yd.	Coating Wt. Between Plies Oz/Sq.Yd.	Adhesion (2in.strip) Lbs	Tensile Lbs/In.
1	W	P	1.3	S	2.05	3.35	0.0	168
2	W	S	2.85	S	1.5	4.35	6.1	165
3	W	S	2.65	S	2.6	5.25	10.4	143
4	W	S	3.1	S	2.4	5.5	8.7	120
5	W	S	1.5	S	3.3	4.8	7.6	159
6	W	S	3.2	P	0.7	3.9	5.7	133
7	W	S	1.6	S	2.95	5.6	12.1	177
		P	1.05					
8	W	S	2.5	S	2.6	5.1	17.4	154
		P-B	1.05					
9	W	S	1.8	S	3.5	5.3	9.6	165
		P-B	1.1					
10	W	S	1.75	S	3.05	4.8	3.0	155
		P-B	1.1					
12	W	S	2.5	S	2.8	5.3	13.7	177
		P-B	1.3					
13	W	S	2.9	S	3.05	5.95	26.1,26.9	173
		P-B	1.3					
15	W	P-B	1.3	P-B	0.5	2.4	1.9,2.0,2.4	189,178
		P	2.0	P	0.4			
16	W	P-B	1.3	P-B	0.5	2.4	1.2,1.6,1.0	185,175
		P	2.0	P	0.4			
17	W	P-B	1.3	P-B	0.5	2.9	4.0,1.0,2.2	163
		P	2.25	P	0.65			

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TABLE XXXV. ADHESION BETWEEN NEOPRENE COATED RR AND HH

COTTON FABRICS (continued)

		RR Cotton		HH Cotton				
Sample No.	Neoprene Type	Type Coating	Wt. Oz/Sq.Yd.	Type Coating	Wt. Oz/Sq.Yd.	Coating Wt. Between Plies Oz/Sq.Yd.	Adhesion (2in.strip) Lbs	Tensile Lbs/In.
18	W	P-B	1.1	P-B	0.5	2.2	2.0,3.2,1.0	133,152
		P	2.0	P	0.2			
19	GRT	P-B	1.3	P-B	0.5	2.7	1.8,0.5,0.0	168,183
		P	2.3	P	0.4			
20	GRT	P-B	0.9	P-B	0.6	3.1	1.8,2.0,1.0	143,167
		P	2.6	P	0.5			
21	GRT	P-B	2.7	P-B	0.4	2.3	4.4,6.0,6.7	172,149
		P	1.9	P	0.4			
22	GRT	P-B	1.0	P-B	0.5	3.9	11.2,10.8,12.1	179,152
		P	2.7	P	1.2			
23	GRT	P-B	1.7	P-B	0.7	3.2	8.0,7.5,8.0	180
		P.	2.3	P	0.9			
24	GRT	P-B	2.1	P	1.2	2.5	4.3,4.0,5.5	180,176
		P	1.3					
25	GRT	P-B	2.4	P	1.5	2.8	11.1,13.2,12.9	185,168
		P	1.3					
26	GRT	P-B	1.4	P	0.8	3.3	9.8,9.0,7.1	167,157
		P	2.5					
27	GRT	P-B	1.9	P	0.8	2.2	4.8,4.0,3.0	166,150
		P	1.4					
28	GRT	P-B	2.2	P	0.5	3.3	6.0,6.9,6.9	177,180
		P	2.8					
29	GRT	P-B	2.2	P	0.70	2.85	8.7,7.8,7.0	171,175
		P	2.15					
30	GRT	P-B	2.4	P	0.95	2.75	13.0,13.3,12.2	187,178
		P	1.8					

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TABLE XXXV. ADHESION BETWEEN NEOPRENE COATED RR AND HH COTTON FABRICS (continued)

Sample No.	Neoprene Type	RR Cotton Type Coating	RR Cotton Wt. Oz/Sq.Yd	HH Cotton Type Coating	HH Cotton Wt. Oz/Sq.Yd.	Coating Wt. Between Plies Oz/Sq.Yd.	Adhesion (2 in. Strip) Lbs	Tensile Lbs/In.
31	GRT	P-B P	1.85 2.05	P	1.18	3.23	12.8,13.8,11.0	154,181
32	GRT	P-B P	0.65 1.9	P	1.15	3.05	5.1,6.3,5.0	175,174
33	GRT	P-B P	0.9 2.0	P	1.25	3.25	16.3,14.0,15.8	162,157

The letters P-B indicate that a knife coating was applied to the back of the fabric.

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TABLE XXXVI. ADHESION BETWEEN NEOPRENE COATED RR AND HH COTTON FABRICS

Sample No.	RR Type	HH Type	Wt. of Coating Between Plies	Oz/Sq.Yd Total	Ratio HH/RR	Adhesion Lbs/2 In.
34	knife	surface	3.45	4.20	0.53	6.5
35	knife	surface	3.25	4.00	0.51	7.0
36	surface	"	3.05	3.75	0.58	11.0
37	"	"	3.55	4.05	0.42	11.2
39	"	"	4.15	5.00	0.38	19.0
40	"	"	3.35	4.20	0.51	15.9
41	"	"	3.45	4.50	0.46	15.8
42	"	"	3.60	4.60	0.50	12.9

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TABLE XXXVII. ADHESION BETWEEN NEOPRENE COATED HH AND BB COTTON FABRICS

Sample No.	HH Type	BB Type	Wt. of Coating Between Plies	Oz/Sq.Yd. Total	Ratio HH/BB	Adhesion Lbs/2 In.
43	none	surface & knife	2.85	2.85	0	0.0
44	surface & knife	none	3.25	3.25	-	5.3
45	knife	surface	3.60	3.60	0.28	6.5
46	surface	knife	3.50	3.50	3.40	2.3
47	knife	surface	3.85	3.85	0.33	5.8
48	surface	surface	3.10	3.10	1.06	8.9
57	surface	surface	2.70	3.30	1.00	5.0
59	surface	surface	4.40	5.50	0.47	11.0
60	surface	surface	4.00	4.70	1.65	13.8

TABLE XXXVIII. ADHESION BETWEEN NEOPRENE COATED THREE-PLY RR, HH, AND BB COTTON FABRICS

Sample No.	Type Coating		Wt. of Coating, Oz/Sq.Yd.					Ratio	Ratio	Adhesion Lbs/2 in	
	RR-HH	HH-BB	RR-HH	HH-BB	RR Back	BB Back	Total	HH/RR	HH/BB	RR-HH	HH-BB
49	S-S	S-S	3.50	2.80	1.10	0.0	7.40	0.67	0.47	16.8	13.2
50	S-P	S-None	4.10	2.95	0.80	1.25	9.10	0.065	----	8.1	0.0
51	S-P	S-P	3.60	3.70	0.85	1.00	9.15	0.075	3.60	8.3	0.0
52	S-P	P-S	3.20	3.80	1.05	1.00	9.05	0.18	0.17	2.2	7.2
54	S-P	S-S	3.90	2.85	1.05	0.95	8.80	0.15	0.97	7.4	13.8
56	S-P	S-S	2.30	3.25	0.50	0.45	6.50	0.53	1.10	12.0	16.8

S = Surface Coated

P = Knife Coated

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TABLE XXXIX. ADHESION OF NEOPRENE COATED NYLON TWILL 31 43

Sample No.	Coating Wt. Between Plies	Oz/Sq.Yd. Front	Back	Total	Ratio T1/T2	Adhesion Lbs/2 In.
NG-7	4.20	0.0	0.0	4.20	1.00	6.5
NG-8	5.15	0.0	0.0.	5.15	1.94	5.5
NG-10	3.10	0.65	0.65	4.40	1.14	5.6
NG-12	5.15	0.75	0.75	6.65	1.06	13.0
NG-13	3.55	0.0	0.0	3.55	0.92	4.5
NG-15	3.55	0.70	0.80	5.05	1.15	8.5
NG-16	5.20	0.75	0.80	6.75	1.21	10.9
NG-17	3.65	0.75	0.65	5.05	0.84	4.1
NF-7	5.55	0.50	0.65	6.70	1.22	9.4
NF-8	2.80	0.60	0.50	3.90	1.00	8.1
NF-9	3.00	0.60	0.55	4.15	1.86	8.8
NH-7	2.90	0.60	0.40	3.90	1.07	7.4
NH-8	2.25	1.15	0.40	4.80	0.83	8.2
NH-9	5.30	0.70	0.65	6.65	1.08	15.3

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TABLE XL. AHESION OF NEOPRENE COATED NYLON BASKET WEAVE (SURFACE) AND NYLON TWILL (KNIFE)

Coating Wt. Oz/Sq. Yd.

Sample No.	Between Plies	Back (BW)	Total	Ratio T/BW	Adhesion Lbs/2 in.
NG-9	4.80	1.10	5.90	0.96	10.2
NG-11	5.15	0.0	5.15	0.71	12.4
NG-14	2.65	0.95	3.65	1.52	9.0
NF-4	2.70	0.90	3.60	1.45	9.5
NF-5	4.30	0.80	5.10	0.54	8.0
NF-6	2.75	0.85	3.60	1.20	10.6
NH-4	3.90	0.95	4.85	0.54	6.2
NH-5	2.35	0.60	2.95	1.35	3.2
NH-6	2.75	0.60	3.35	1.20	9.7

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TABLE XLI. ADHESION OF NEOPRENE COATED NYLON BASKET WEAVE AND NYLON TWILL (all knife coated)

Sample No.	Coating Wt. Oz/Sq. Yd. Between Plies	Back(BW)	Total	Ratio T/BW	Adhesion Lbs/2 In.
NG-1	3.15	1.10	4.25	1.33	6.3
NG-2	2.25	0.95	3.20	2.21	0.0
NG-3	3.75	0.80	4.55	1.03	5.5
NG-4	3.25	0.95	4.20	0.63	3.8
NG-5	3.95	1.10	5.05	1.20	13.0
NG-6	4.57	0.90	5.47	1.03	14.9
NF-1	2.80	1.70	4.50	1.45	6.4
NF-2	3.65	0.75	4.40	0.97	14.0
NF-3	4.30	0.65	4.95	0.79	12.0
NH-1	2.35	0.50	2.85	0.96	1.5
NH-2	3.65	0.65	4.30	0.97	12.5
NH-3	3.45	0.65	4.10	0.77	12.0

TABLE XLII. ADHESION OF NEOPRENE COATED NYLON BASKET WEAVE AND NYLON TWILL - THREE PLY FABRIC

Sample No.	Basket-Twill	Twill-Twill	Basket-Back	Twill Back	Total	Ratio T/BW	Ratio T1/T2	Adhesion, Lbs/2 In. BW-T	Adhesion, Lbs/2 In. T1-T2
NG-18	3.70	2.90	0.90	0.70	7.20	1.31	0.87	12.6	8.7
NG-19	4.45	5.05	0.75	0.65	10.90	0.82	1.02	9.1	9.8
NG-20	5.30	4.90	0.75	0.70	11.65	0.73	0.96	14.4	10.7
NF-10	2.65	2.65	0.70	0.60	6.60	1.30	0.96	10.1	8.2
NF-11	4.35	5.75	0.85	0.55	11.50	0.81	0.98	7.9	14.7
NF-12	3.75	4.30	0.70	0.65	9.40	0.79	0.87	7.5	12.0
NH-10	2.65	2.35	0.60	0.60	6.20	1.41	0.74	7.7	6.0
NH-11	3.90	4.70	0.80	0.35	9.75	0.77	0.88	9.9	10.7
NH-12	3.65	4.40	0.70	0.40	9.15	0.99	0.66	8.8	6.6

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TABLE XLIII. EFFECT OF ADHESIVES ON ADHESION OF NYLON TWILL TO NYLON TWILL

Adhesive Type	Wt.oz/sq.yd. T_1	Wt.oz/sq.yd. T_2	Coating Wt.oz/sq.yd. Between Plies	Coating Wt.oz/sq.yd. Total	Ratio T_1/T_2	Adhesion Lbs/2 In.
Resorcinol Formaldehyde Gentac Latex (1)	0.5	0.5	3.10	4.10	1.14	7.4 (3)
Resorcinol Formaldehyde Gentac Latex (2)	0.5	0.5	2.50	3.50	1.00	12.4 (3)
20% MDI - Neoprene	0.5	0.5	4.50	5.50	1.00	18.7 (3)
20% MDI - Neoprene	0.3	0.3	2.55	3.13	1.32	14.6 (3)
10% MDI - Neoprene	0.45	0.5	3.40	4.30	0.75	8.4 (4)
15% MDI - Neoprene	0.5	0.6	2.70	3.80	0.50	17.2 (4)
15% MDI - Neoprene	0.5	0.5	2.80	3.90	0.55	15.6 (4)
10% MDI - Neoprene	1.5	1.45	2.60	5.55	0.63	14.2 (4)
15% MDI - Neoprene	1.45	1.1	2.20	4.75	0.50	17.2 (4)

(1) Aged 6 hours before application
(2) Aged 23 hours before application
(3) Scoured fabric
(4) Greige fabric

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TABLE XLIV. EFFECT OF ADHESIVES ON ADHESION OF NYLON BASKET WEAVE TO NYLON TWILL (SCOURED AND HEAT SET)

Type	Wt. oz/sq.yd BW	Wt. oz/sq.yd T	Coating Wt. oz/sq.yd. Between Plies	Back Bw	Back T	Total	Ratio T/BW	Adhesion Lbs/2 In.
20% MDI - Neoprene	0.4	0.35	4.1	0	0	4.1	1.16	12.4
"	0.5	0.25	5.1	0	0	5.1	1.80	18.2
"	0.55	0.35	7.25	0	0	7.25	0.98	41.2
15% MDI - Neoprene	0.55	0.35	5.5	0.7	0.75	6.95	1.87	20.2
"	0.5	0.3	5.1	0.55	0.75	6.40	1.87	16.4
"	0.5	0.25	4.95	0.5	0.70	6.15	1.80	14.5
9% MDI - Neoprene	1.25	0.3	4.75	0.7	1.1	6.55	1.91	11.7
"	0.80	0.3	4.55	0.5	0.8	5.85	1.23	9.2
"	0.50	0.3	4.35	0.75	0.7	5.85	1.29	9.8
20% MDI - Neoprene	0.32	0.3	4.12	0.78	0.9	5.80	0.95	16.0
"	0.25	0.4	4.1	0.95	0.8	5.85	1.67	17.5
"	0.60	0.4	4.2	0.65	0.95	5.80	1.17	23.0

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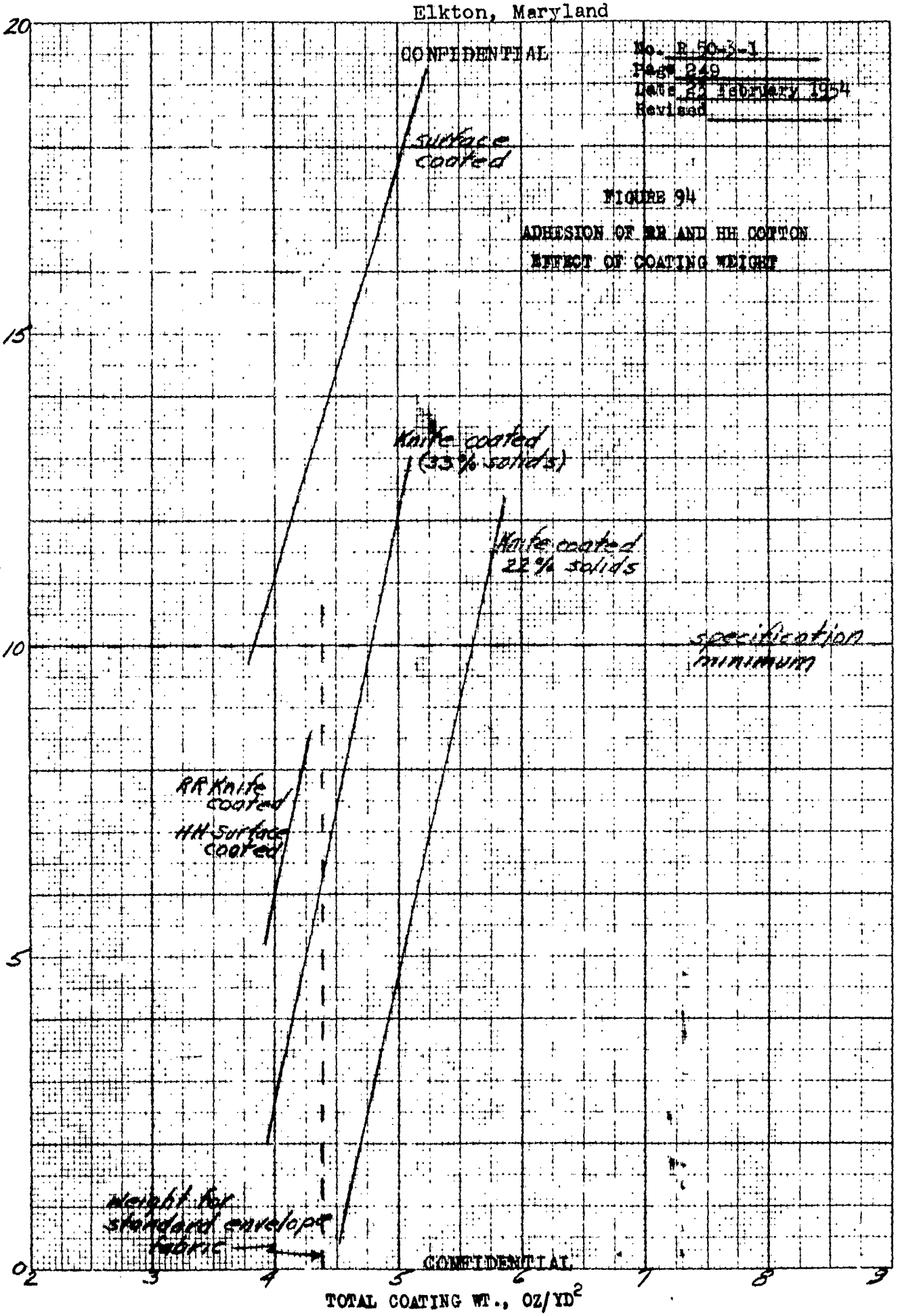

FIGURE 94

ADHESION OF RR AND HH COTTON
EFFECT OF COATING WEIGHT

NO 340/ 20 DIETZGEN GRAPH PAPER
20 X 20 PER INCH
EUGENE DIETZGEN CO.
MADE IN U. S. A.

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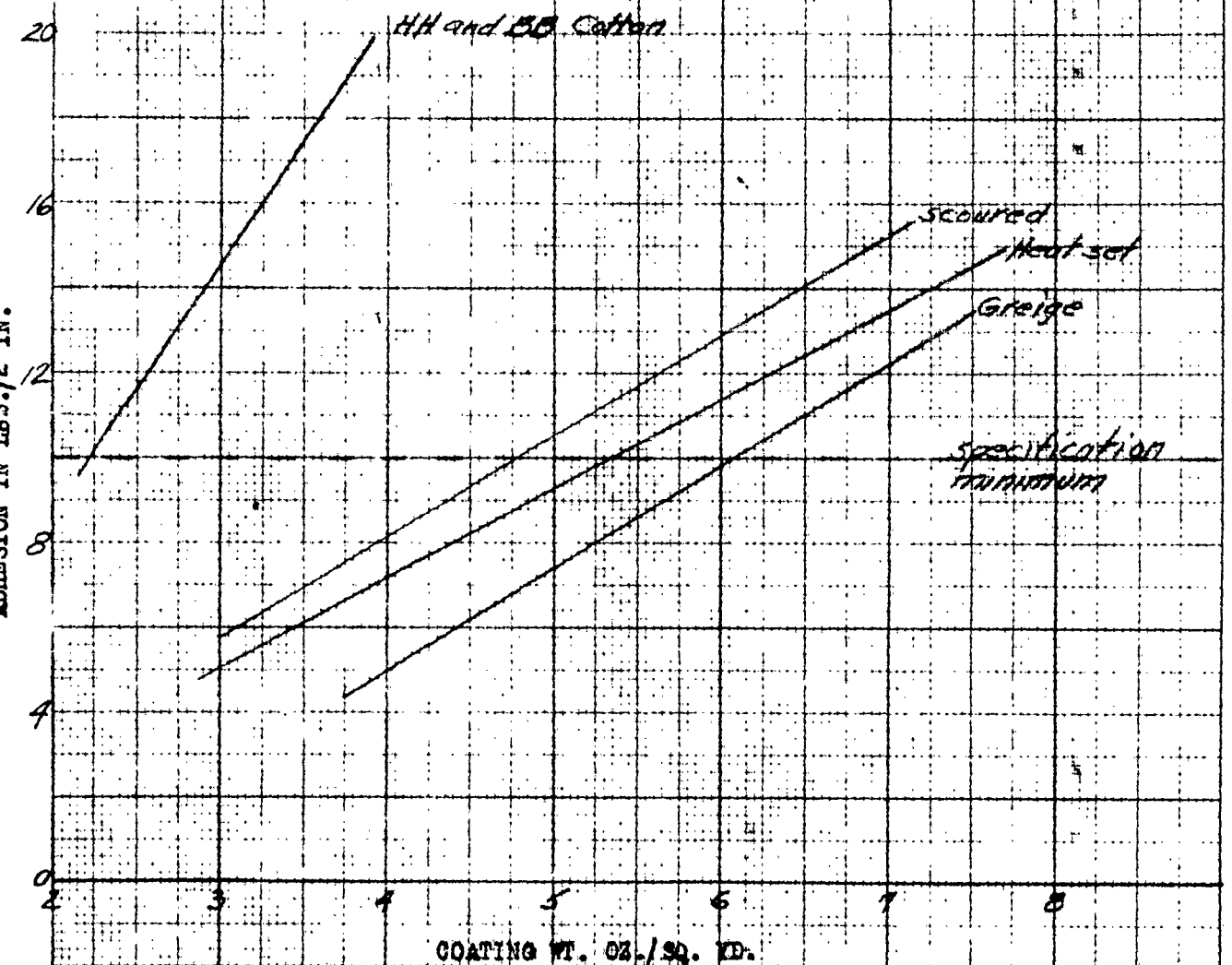
FIGURE 95
EFFECT OF COATING WEIGHT ON ADHESION
NYLON TWILL 3143



EUGENE DIETZGEN CO. MADE IN U.S.A.
NO 340/ 20 DIETZGEN GRAPH PAPER 20 X 20 PER INCH

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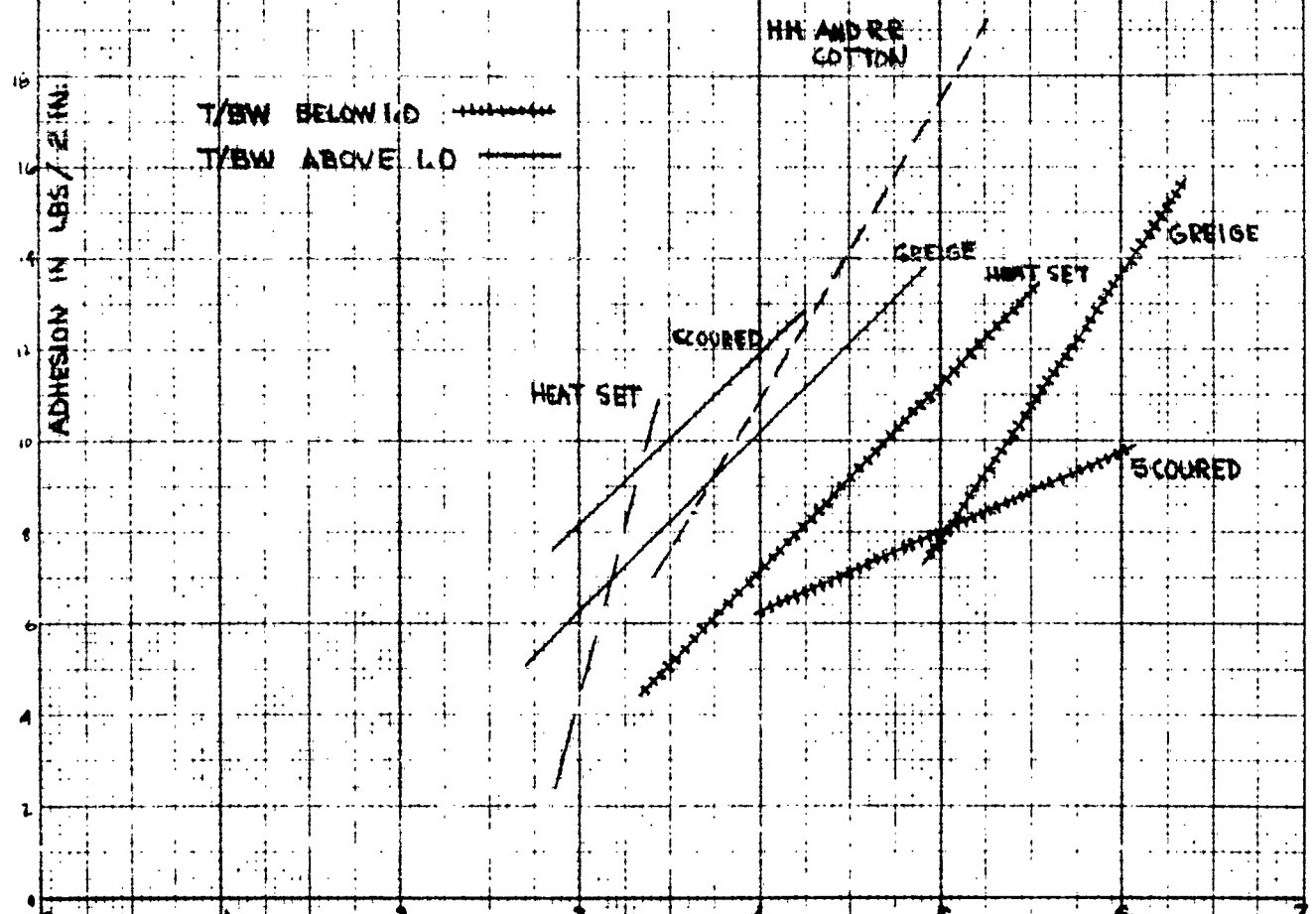
FIGURE 96

EFFECT OF COATING WEIGHT ON ADHESION
NYLON BASKET WEAVE 3142 AND NYLON TWILL 3143
(SURFACE COATED BW, KNIFE COATED T)



EUGENE DIETZGEN CO
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NO 340 20 DIETZGEN GRAPH PAPER
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FIGURE 97

EFFECT OF COATING WEIGHT ON ADHESION
NYLON BASKET WEAVE 3142 AND NYLON TWILL 3143
(ALL KNIFE COATED)

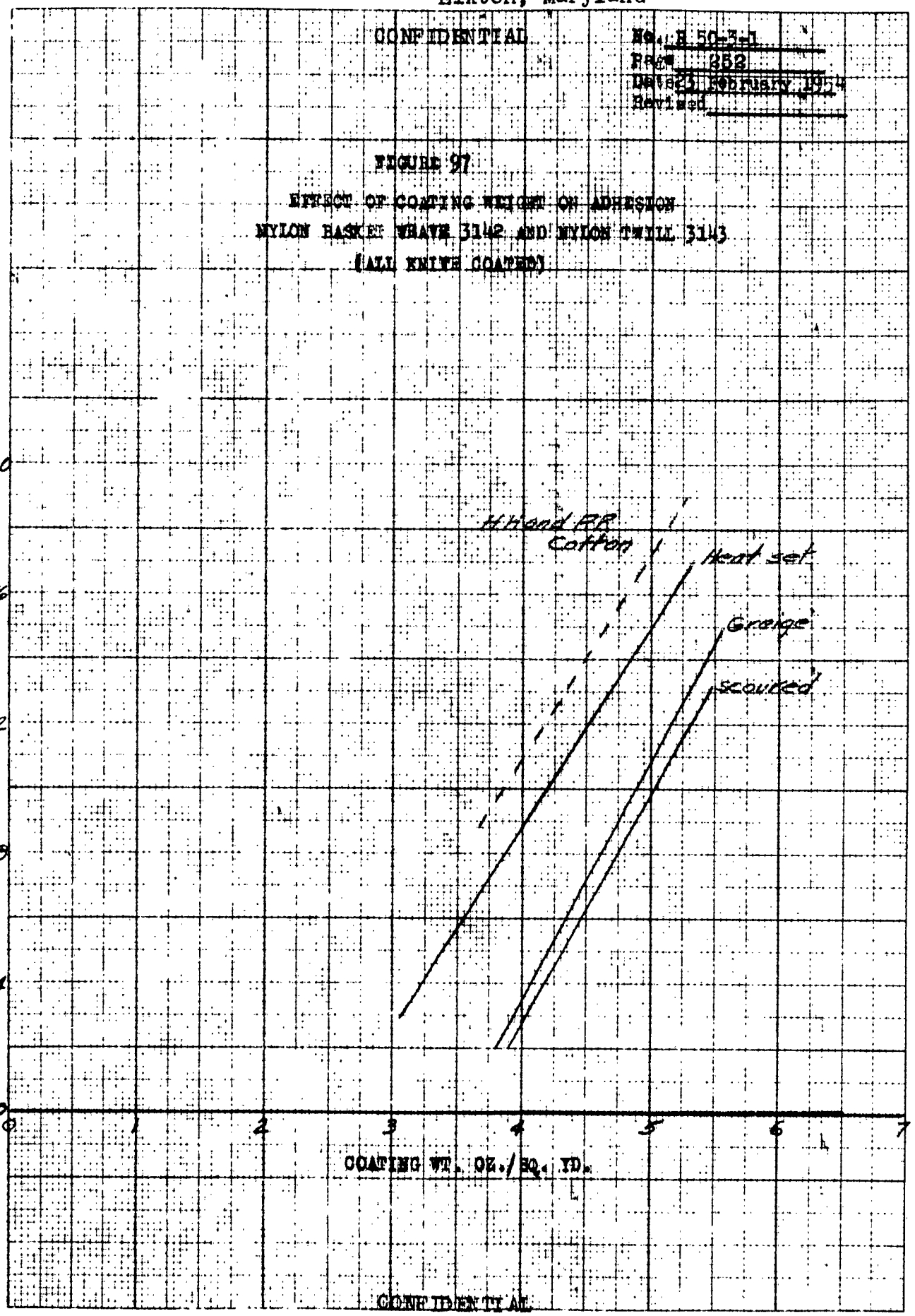

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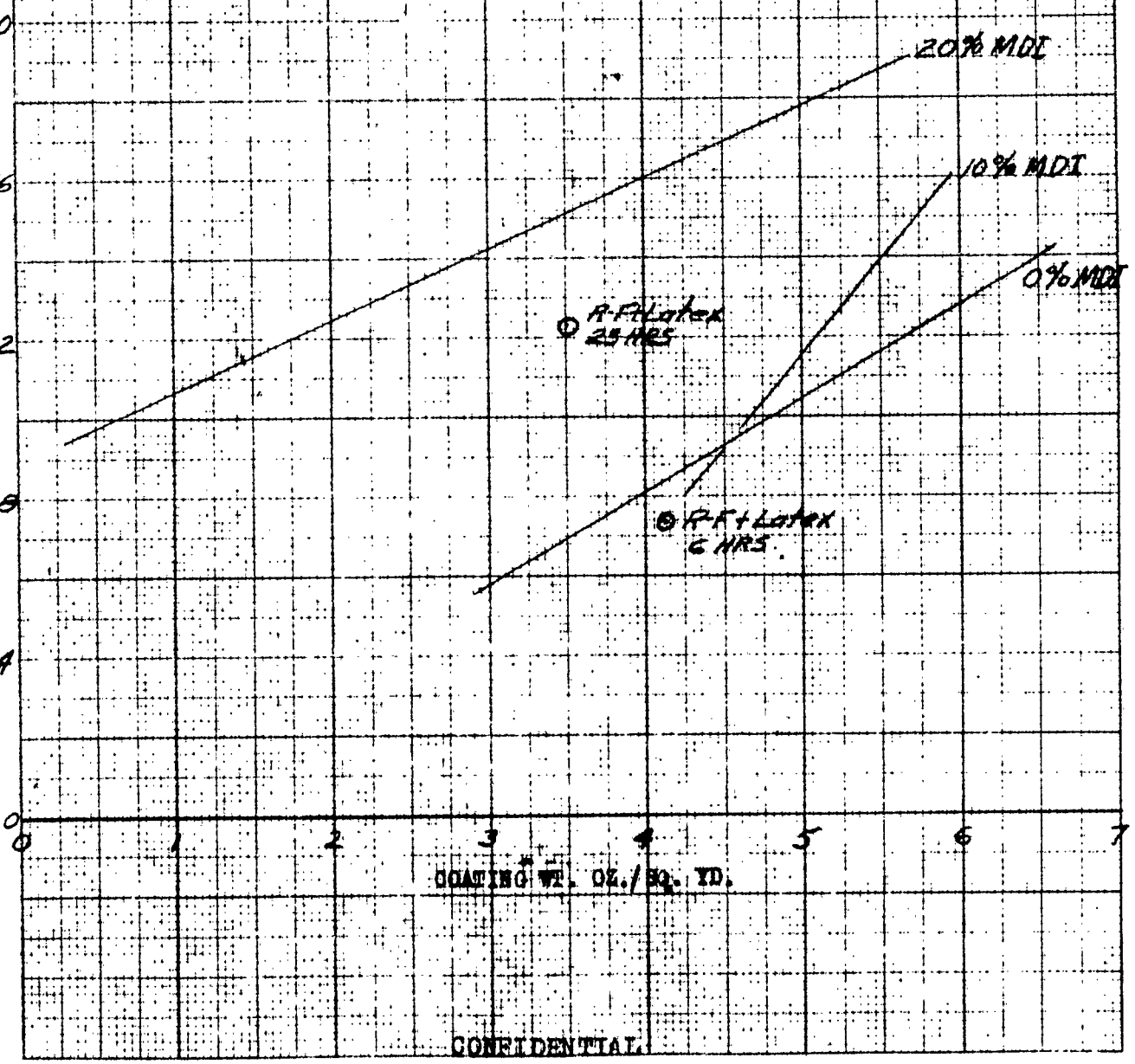
FIGURE 9E

EFFECT OF ADHESIVES ON ADHESION

NYLON TWILL 3143



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5.3.2.3 Permeability

The permeability of a few samples of Neoprene coated fabrics was determined on the Cambridge Permeameter. The results are tabulated below:

TABLE XLV. PERMEABILITY OF COATED FABRICS

Fabric	Type Coating	Coating Wt. Oz/Sq. Yd.	Permeability Liters/Sq. Meter/24 hrs.
HH	S	3.0	5.2
	S	2.8	6.0
	S	4.8	2.8
	S	3.7	7.2
RR	P	2.9	many pin holes
	S	1.1	" " "
	S	4.0	5.5
2941	S	3.3	90
Standard 3 Ply	----	9.9	1.9

Most of the samples meet the permeability requirements with one coat of Neoprene. If adhesion specifications can be met, this technique should make it possible to produce a 3-ply envelope fabric with less Neoprene than is now used.

Experiments on coating weight versus permeability were carried out on three different nylon fabrics to determine the effect of weave. The results are summarized in Table XLVI. These show that a smooth plain weave may give better results than a twill. In all cases the

fabrics are surface coated.

Permeability of two-ply fabrics was measured. The results are given in Table XLVII. The cotton fabrics show decreasing permeability with increasing coating weight. The nylon fabrics, however, show no regular correlation between weight and permeability. The surface coated samples, in general, have lower permeabilities than the knife coated samples.

It is believed that three-ply fabrics have been used because of difficulty in obtaining low permeability with a two-ply basket weave and twill combination. A coating between two fine weave fabrics has been necessary. The surface coating method promises to overcome this difficulty. Improved techniques should eliminate many of the variations now present.

Indications are that if adhesion is high enough, permeability changes very little.

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TABLE XLVI. EFFECT OF COATING WEIGHT ON PERMEABILITY

Fabric	Fabric Wt. Oz/Sq.Yd.	Coating Wt. Oz/Sq.Yd.	Permeability L/Sq.M/24 hrs.
Nylon 3143	2.85	3.10	4.30
Heat Set Twill		2.45	pff scale 90 secs.
		1.55	pin holes
		1.45	off scale 10 secs.
Nylon 2887	2.97	3.20	5.0
Heat Set Twill		2.70	22.9
		1.95	pin holes
Nylon 5324	1.75	2.80	8.4
Plain Weave		2.65	17.0
		1.75	pin holes
		1.15	pin holes

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TABLE XLVII. PERMEABILITY OF PLIED FABRICS

Fabrics	Type of Coating*	Coating Wts. Oz/Sq.Yd. Between Plies	Front	Back	Total	Total Wt. of Combination Oz/Sq.Yd.	Permeability L/Sq.M./24 hrs.
HH-BB	S	2.70	0.35	0.25	3.30	8.05	11.0
HH-BB	S	3.65	0.0	0.25	3.90	8.65	4.6
HH-BB	S	4.40	0.35	0.30	5.50	10.25	3.2
3143-3142 Nylon	S	4.10	0.0	0.0	4.10	10.95	Off Scale
	S	4.35	0.70	0.75	5.80	12.65	0.4
	S	4.55	0.80	0.50	5.85	12.70	0.5
	S	4.75	1.10	0.70	6.55	13.40	0.5
	S	4.95	0.70	0.50	6.15	13.00	Off Scale
	S	5.10	0.75	0.55	6.40	13.25	Off Scale
	S	5.10	0.0	0.0	5.10	11.95	3.3
	S	5.50	0.75	0.70	6.95	13.80	1.3
	S	7.25	0.0	0.0	7.25	14.10	1.7
	P	2.85	0.50	0.55	3.90	10.30	28.5
	P	3.25	1.30	1.53	6.08	12.48	41.0
	P	3.80	0.75	0.70	5.25	11.65	90.0
	P	4.80	0.85	0.70	6.35	12.75	14.0
	P	4.95	1.35	0.80	7.10	13.50	Off Scale
	P	5.06	0.42	0.42	5.90	12.30	0.9
	P	5.45	0.55	0.60	6.60	13.00	1.2
	P	5.65	0.85	0.55	7.05	13.45	0.8
	P	5.65	0.10	0.25	6.00	12.40	68.0
	P	5.90	1.15	1.00	8.05	14.45	72.0
	P	6.45	2.05	1.30	9.80	16.20	36.0

*S = Surface coated, P = Knife coated

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5.3.2.4 Rotoflex Tests

Present specifications call for a Rotoflex test of twenty cycles at 180 cycles per minute in each of four directions of the fabric, with a load of 880 grams. The time for each direction then is 7 seconds. Changes in permeability and tensile strength are determined.

Initial tests with a Rotoflex tester operated at 200 cycles per minute showed large changes in permeability in some samples and very little in others. The results seemed to show that little change in permeability was related to a high adhesion or high weights of Neoprene. This led to an intensive study of the Rotoflex test.

The standard cotton envelope fabric (3-ply) was studied first. A sample was Rotoflexed again for an additional time, using 880 gm weight. This was continued until the total time was 1 hour. Permeability changes from 1.6 initially to 3.5 liters/meter^2/24 hrs. Then a series of samples was run, each for a definite time. Permeability and tensile strength were determined. Permeability changed little, but the tensile strength dropped from 186 lbs/in. to 114 lbs/in. after 1 hour. The curve is shown in Figure 99. No change is apparent after the normal time of 7 seconds, but considerable change takes place after longer times of Rotoflexing.

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Samples of plied nylon and Dacron fabrics from the first pilot plant run were Rotoflexed. Results are shown in Table XLVIII.

All these results show that initial permeability varied only slightly with weight of Neoprene. Samples containing the most Neoprene break-down less readily during Rotoflexing. The weight of Neoprene required, and therefore, the total weight of fabric will be determined by the time set for any new Rotoflex test specification.

The effect of Rotoflex time on tensile strength of these fabrics and others is illustrated by the curves in Figure 100.

In some cases, large changes in permeability took place. Dacron samples also showed a decrease in tensile strength. The samples with the highest total weight, and therefore the most Neoprene, gave the best results.

Plied fabrics from the second pilot plant run were tested in the same manner. Results are shown in Table XLIX.

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TABLE XLIX. ROTOFLEXED FABRICS - PILOT PLANT RUN #2

Fabric	Wt. of Neoprene Between Plies Oz./Sq. Yd.	Total Wt. Plied Fabric Oz/Sq.Yd.	Time of Rotoflexing Mins. #	Permeability $L/M^2/24$ hrs.	Tensile Strength Lbs/In.	Adhesion Lbs/In.
Nylon	3.60	13.75	0	3.8	241	9.1
			1	20.0	240	
Nylon	6.10	16.5	0	2.0	250	10.8
			1	5.0	--	
			6	5.4	--	
			10	6.5	241	
Dacron	5.20	17.55	0	2.1	256	8.0
			1	6.6	252	
Dacron	5.00	17.6	0	2.0	256	
			1	2.0	--	9.0
			6	4.5	--	
			10	12.8	217	

880 gm wt. used

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FIGURE 99
EFFECT OF ROTOFLEX TIME
ON TENSILE STRENGTH
STANDARD COTTON ENVELOPE

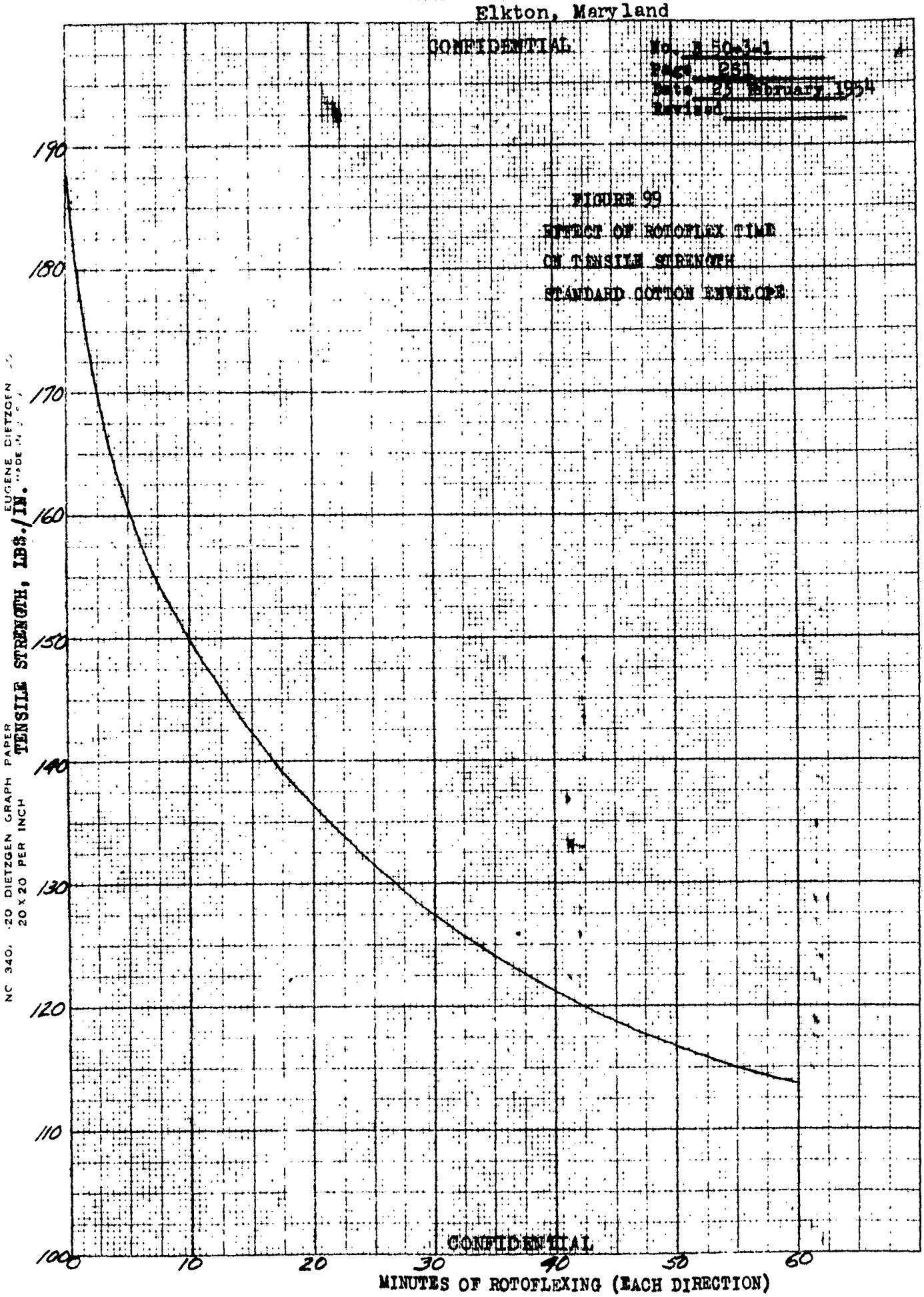

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FIGURE 100
EFFECT OF ROTOFLEX TIME
ON TENSILE STRENGTH
OF COATED PLIED FABRICS

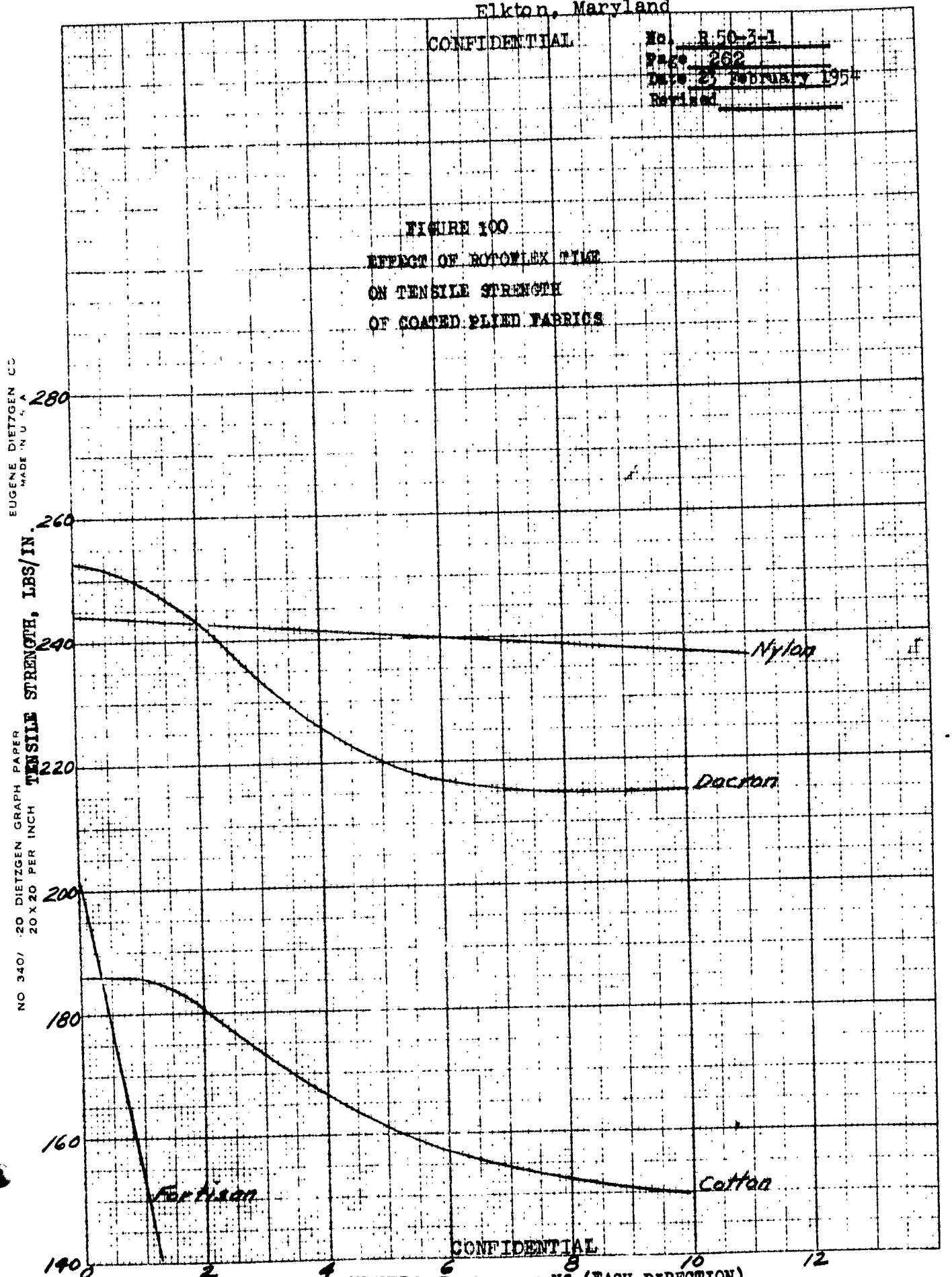

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TABLE XLVIII. ROTOFLEXED FABRICS - PILOT PLANT RUN #1

Fabric	Wt. of Neoprene Between Plies Oz/Sq.Yd.	Total Wt. Plied Fabric Oz/Sq.Yd.	Time of Rotoflexing Mins. *	Permeability $L/M^2/24$ hrs.	Tensile Strength Lbs/In.	Adhesion Lbs/In.
Nylon	4.60	13.7	0	1.2	244	8.7
			1	18.4	--	
			5	off scale	240	
Nylon	5.25	13.2	0	5.6	230	8.7
			1	off scale	243	
Nylon	6.80	16.15	0	0.7	237	8.0
			1	1.0	--	
			11	14.4	232	
Dacron	4.43	15.3	0	3.6	251	8.5
			1	64.0	250	
Dacron	3.57	15.45	0	3.5	266	5.0
			1	34.0	--	
			5	Off scale	242	
Dacron	4.92	16.2	0	1.3	226	7.0
			1	3.1	--	
			11	4.8	190	

*880 gm wt. used

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5.3.2.5 Latex Seal Coats

A different technique was studied for keeping the Neoprene coating on the surface of fabrics. This consists of sealing the fabric with a small amount of Neoprene latex compound. The seal coat prevents penetration of subsequent solvent Neoprene coats. This allows the application in one coat of the minimum amount of Neoprene necessary for adhesion and permeability. Without the seal coat, the same amount of Neoprene soaks into the fabric, resulting in poor adhesion and formation of pinholes.

Neoprene latex and Polyblend latex 552 were used for seal coats on cotton and nylon. The results summarized in Table L show that low permeability is attained with one solvent coat. For HH-BB cotton plies the total weight is close to that of this portion of the standard envelope fabric. The 3143-3142 nylon fabric combination is strong enough not to require another ply. The total weight, therefore, is much less than the weight of the standard 3-ply cotton fabric (10.85 vs. 15.95) without the inside and outside coats.

Permeability of the samples without front and back coats would be reduced if these coats were applied.

Table L lists also the results obtained with resorcinol formaldehyde resin and stabilized tolylene diisocyanate (TDI) in the latex seal coat. Both these

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additives improved adhesion. Resorcinol formaldehyde resins give unstable latex compositions. The stabilized isocyanates do not, so they are preferred as additives. In preliminary work a sample without additive had an adhesion of 10.0 lbs/2 in.

The same latex with acetone oxime stabilized TDI gave an adhesion of 21.0 lbs/2 in., and with phenol stabilized TDI an adhesion of 29.0 lbs/2 in.

Normal isocyanates are very reactive toward water and cannot be used in latex compositions. The stabilized compounds are unreactive in latex and during drying to remove water. Upon heating to cure the Neoprene, however, the compounds decompose to liberate free isocyanates. These then can act to improve adhesion in the same manner as an isocyanate applied from an organic solvent.

More work is planned with the latex seal system containing TDI and other isocyanate compounds.

TABLE L. COMPOSITION AND PROPERTIES OF LATEX

SEALED PLIED FABRICS

Fabrics (1)	(2)	Coating Wt. Oz/Sq.Yd. Seal Coats (1)	(2)	Solvent Coats Back	Middle	Front	Total Wt. of Plies Oz/Sq.Yd.	Adhesion Lbs/2 In.	Permeability L/sq.M/24 hrs.
HH - BB[1]		0.0	0.0	0.0	3.3	0.0	7.55	17	-
HH - BB		0.44	0.50	0.0	2.15	0.0	7.84	-	8.1
HH - BB		0.52	0.47	0.0	2.43	0.0	8.17	-	3.0
3143-3142		0.76	1.10	0.0	2.99	0.0	10.85	11.0	3.0
3143-3142[2]		0.88	1.64	0.58	5.32	0.29	15.60	20.0	2.7
3143-3142[3]		(4)	(4)	(4)	4.33	(4)	14.20	33.4	2.8

(1) Standard cotton envelope combination
(2) Latex with resorcinol formaldehyde resin
(3) Latex with stabilized tolylene diisocyanate
(4) Weight of seal coats and front and back coats not determined separately. Total on 3143 is 1.05, on 3142 is 1.93

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Additional work was carried out with the latex seal coat method using stablized diisocyanate to improve adhesion.

Scoured, heat-set nylon 3142 and 3143 were sealed with this latex compound and then coated with Neoprene solution. Various coating weights were used to determine the effect of coating weight on permeability. The results are given in Table LI. Permeability decreases with increasing coating weight.

TABLE LI. PERMEABILITY OF LATEX SEALED FABRICS

Fabric	Wt. of Neoprene, Oz/Sq.Yd. Latex	Solvent	Total	Permeability $L/M^2/24$ hrs.
3143	0.80	1.17	1.97	11.5
3143	0.74	2.20	2.94	8.7
3143	0.78	2.05	2.83	8.8
3143	0.78	3.67	4.45	5.9
3142	1.40	1.08	2.48	24.0
3142	1.56	1.62	3.18	7.8
3142	1.51	2.53	4.04	6.0
3142	1.56	3.47	5.03	5.2

A series of plied scoured, heat-set 3142 and 3143 nylon fabrics was made to determine the reproducibility of permeability and adhesion, and the variation in these properties with amount and distribution of Neoprene between plies. The results are summarized in Table LII.

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TABLE LII. COMPOSITION AND PROPERTIES OF PLIED NYLON FABRICS - LATEX SEALED

Wt. of Neoprene, Oz/Sq.Yd. 3143	3142	Between Plies	Permeability, $L/M^2/24$ hrs. Initial	10 Min. Roto.*	Adhesion Lbs/In.
2.17	2.65	4.63	6.0	6.3	7.8
2.17	3.34	5.21	5.0		
1.87	3.82	5.41	4.3		
1.87	5.26	7.36	3.7	3.0	9.3
2.61	2.65	4.91	5.3		9.1
2.61	3.34	5.71	5.0		
2.47	3.82	6.21	4.3		
2.47	5.26	7.71	3.6		8.9
3.58	2.86	6.50	4.2		
3.58	3.73	7.39	3.8	3.4	10.9
3.11	3.73	6.91	3.9		
3.11	4.87	8.11	3.2		
6.17	2.86	7.61	3.7	3.3	12.3
6.17	3.73	8.31	3.2		10.0
4.58	3.73	8.03	3.3		10.0
4.58	4.87	9.91	2.8		12.8

* 880 gm load

All the samples had permeabilities below 8 $L/M^2/24$ hrs. Results were consistent. The samples which were Rotoflexed for 10 minutes showed no change in permeability.

Adhesion increases slightly with increase in the amount of coating between plies. For a given coating composition, adhesion depends more upon the method of plying. This is shown by the results on samples made from the same fabrics, but plied under different conditions. Heat and pressure should be used.

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TABLE LIII. EFFECT OF PLYING METHOD ON ADHESION

Method	Adhesion, Lbs/In.
Squeeze rolls, cold sample	6.3
Squeeze rolls, sample at 300°F.	16.1
Carver press, 400 PSI, cold	25.4
Carver press, 400 PSI, 160°F.	over 25, sample tore

A better understanding of permeability properties of latex sealed fabrics was sought. If the reciprocals of permeability values in Tables LI and LII are plotted against total weight of Neoprene, the points form a straight line through the origin. (Figure 101). The slope of the line is 0.037 L^{-1} M^2 24 hours, $oz.^{-1}$ $yd.^2$ which corresponds to 27.0 LM^{-2} 24 hrs. $^{-1}$ oz. $yd.^2$. The literature value in the same units for Neoprene is 23.8. This agreement shows that the method of coating used gives the same permeability as an unsupported film of the same weight.

Coated fabrics with permeabilities lower than those of free films can be made. Scoured, heat-set nylons 3142 and 3143 were sealed with latex and then spread with various weights of Neoprene on the unsealed side. This, in effect, saturates the fabric.

After curing, permeability was determined with the results shown in Table LIV. All samples show the effect of the fabric in lowering permeability.

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TABLE LIV. EFFECT OF FABRIC HELP ON PERMEABILITY

Fabric	Weight of Neoprene Oz/Sq. Yd.	Permeability, L/M^2 24hrs. Actual	Calc. Free Film
3143	2.01	10.4	13.4
3143	2.65	6.5	11.2
3143	3.20	4.4	8.5
3143	4.95	2.6	5.5
3142	3.68	4.6	7.3
3142	4.34	4.8	6.2
3142	5.09	3.1	5.3

Attempts to make plied fabrics using the above coating method were unsuccessful. Low permeability with good adhesion could not be obtained. Also, permeability increased after Rotoflexing.

If fabric was treated to saturate the yarns and then coated, the fabric should give maximum help in preventing diffusion of gas. Such a sample was made by impregnating scoured, heat-set nylon 3143 with Neoprene latex (0.72 oz/sq. yd.), sealing with Neoprene latex plus isocyanate (0.84 oz/ sq. yd.), and spreading with Neoprene solution.

Total weight of Neoprene was 6.37 oz/sq.yd. Initial permeability was 1.7 $L/M^2/24$ hrs., and 1.9 $L/M^2/24$ hrs. after two minutes Rotoflexing (3000 grams). Equivalent unsupported film permeability is 4.2 $L/M^2/24$ hrs. which shows that the fabric itself is acting as part of the gas barrier.

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Plied samples made by the impregnation method did not have low permeability and broke down after Rotoflexing. This may be because the coating contained craters which made thin spots in the coating.

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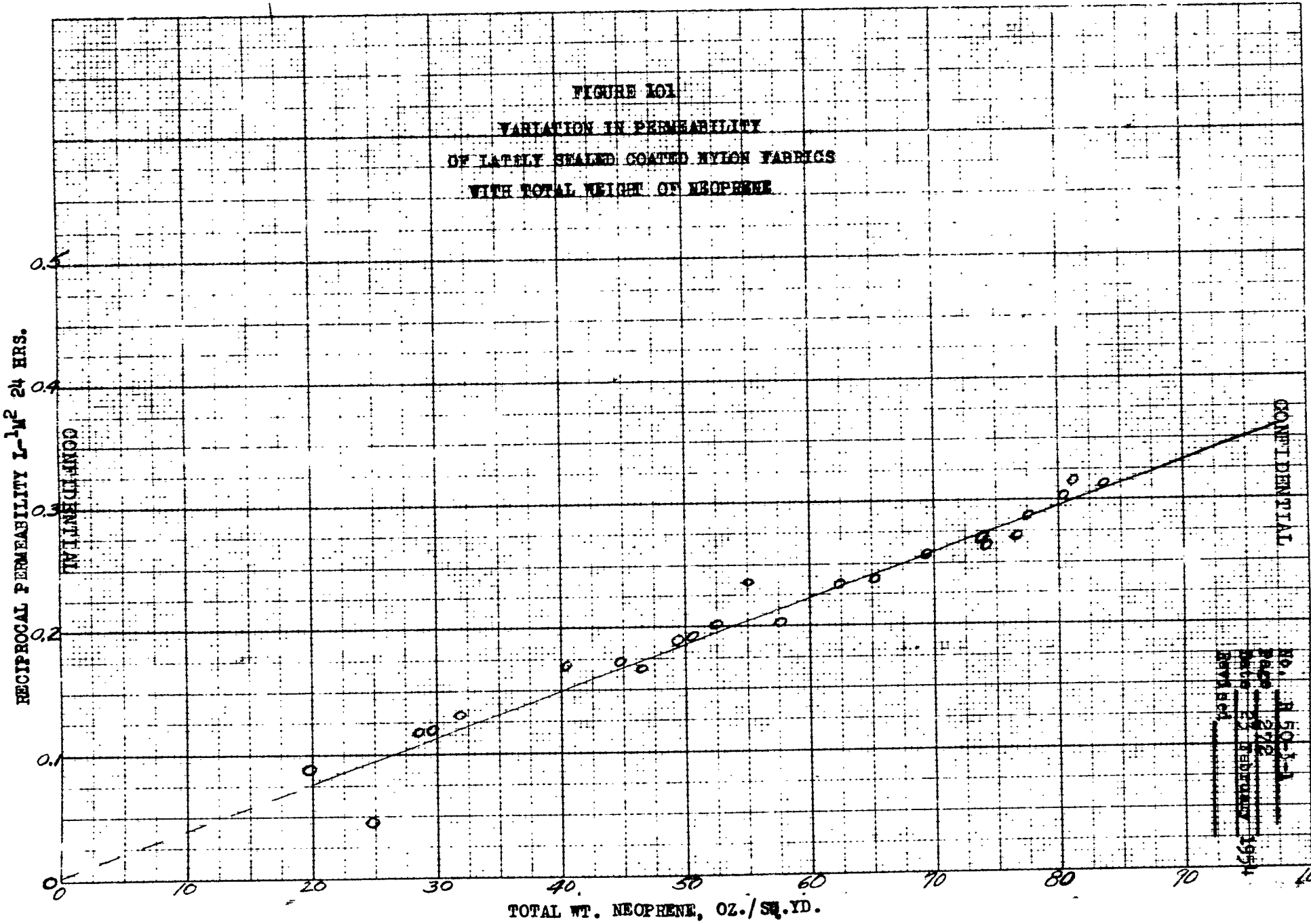
FIGURE 101

VARIATION IN PERMEABILITY

OF LATELY SEALED COATED NYLON FABRICS

WITH TOTAL WEIGHT OF NEOPRENE



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Another method of making plied fabrics was tried, still using the impregnation technique to obtain fabric help. Nylon basket weave 3142 was knife coated on each side with Neoprene latex, and again on one side with Neoprene solution. Nylon twill 3143 was impregnated with Neoprene latex-isocyanate compound and then sandwiched between two dry films of Neoprene coated on Holland cloth. The Holland cloth was stripped and the surface plied on a bias to the primed (neoprene sol.) 3142 surface. Plying was completed by pressing the sample under 140 lbs/sq.in. at 150°F. for five seconds. The sample then was cured. It has the following composition:

Outside film	1.57 oz/sq.yd.
3143 Impregnation	0.56 "
Inside film	4.01 "
3142 Primer and inside coat	2.27 "
Total Neoprene	8.41 "

The permeability was measured before and after Rotoflexing and compared with the standard cotton envelope fabric.

	Nylon	Cotton
Initial permeability	2.1	1.9
Permeability 5 min. Rotoflex	2.3	2.8
" 10 min.	3.0	3.1
" 20 min.	2.9	3.2

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Several other samples were made by the same method. Permeability increased after Rotoflexing. This may be due to film damage during stripping from the Holland cloth. Since the basic idea of impregnation is sound, various modifications will be tried to develop better methods of making plied fabrics.

Some excellent, but inconsistent, results were obtained by impregnating fabrics with a latex compound, coating with Neoprene solution, and plying with heat and pressure. Impregnation increased the fabric help ratio, which results in low permeability at a minimum coating weight. This effect was studied in more detail because of its importance in reducing the total weight of the plied fabric.

Samples of greige heat-set nylon 3143 were impregnated with Neoprene latex compound containing stabilized diisocyanate. They then were sealed with two coats of the same compound thickened with methyl cellulose. Finally they were coated with solvent Neoprene, dried, and cured. Results are shown below. (Table on next page).

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Weight of Coatings, Oz/Sq.Yd.					
Latex Impreg.	Latex Seal	Solvent Neoprene	Total	Permeability $L/M^2/24$ hrs.	F.H. Ratio
0	0.52	3.14	3.66	7.0	1.06
0.29	0.57	3.08	3.94	6.0	1.15
0.54	0.55	3.09	4.17	4.8	1.35
0.70	0.57	3.17	4.44	4.1	1.49
1.20	0.41	3.19	4.80	4.2	1.33

The fabric help ratios increase with increasing amounts of impregnation, except for the last sample. The ratios are much lower than that of the first sample prepared by impregnation (F·H. Ratio 2.49). The presence of warp size was considered as the cause, so the tests were repeated with scoured heat-set nylon 3143.

Weight of Coatings, Oz/Sq.Yd.					
Latex Impreg.	Latex Seal	Solvent Neoprene	Total	Permeability $L/M^2/24$ hrs.	F.H. Ratio
0	0.80	3.09	3.89	6.3	1.10
0.23	0.69	3.04	3.96	5.1	1.33
0.37	0.73	3.14	4.24	4.5	1.41
0.50	0.81	3.40	4.81	3.3	1.70
1.03	0.80	3.27	5.10	2.7	1.96

Again the fabric help ratio increased with increased amounts of impregnation. The ratios are higher than for the greige fabric. Another series was run to further establish this effect of scouring, and also to find the effect of the weight of surface coating on the fabric help ratio.

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Fabric	Weight of Coatings, Oz/Sq.Yd. Latex Impreg.	Latex Seal	Solvent Neoprene	Total	Permeability $L/M^2/24$ hrs.	F.H. Ratio
Scoured Heat-Set	0.71	0.82	2.89	4.42	3.8	1.61
Greige Heat-Set	0.78	0.50	2.87	4.15	4.0	1.62
Greige Heat-Set & Scoured	0.75	0.62	3.06	4.47	4.8	1.26
"	0.75	0.62	5.37	6.74	3.7	1.08

These results contradict the earlier ones. The greige heat-set fabric gives the same fabric help as the scoured heat-set one. Scouring the greige heat-set fabric decreases fabric help. Some factor other than fabric treatment must be responsible for the differences observed.

Coating weight has little effect on fabric help in the range studied. The sample with the heavier coating has a lower ratio. This is due to fabric help having a proportionally lower effect as coating weight increases. Its effect always will be greater percentage-wise for lighter films.

The factor referred to above as being responsible for variations in fabric help may be the sponging of the coating. This can occur during decomposition of the stabilized diisocyanate in the curing operation. A comparison was made of samples with and without stabilized diisocyanate in the impregnating latex. The sample without the additive had the higher fabric help ratio.

Since some additive is needed to obtain adhesion,

the effect of reducing the amount was determined. The lowest amount tried, 7.2 parts, is satisfactory.

Parts of Additive Per 100 Parts Neoprene	Adhesion Lbs/In.
28.7	23.9
14.4	34.0
7.2	24.5
0.0	8.5

Two samples of plied fabric were made using greige heat-set nylon 3142 and 3143. The 3143 fabric was impregnated with Neoprene latex containing 7.2 parts of stabilized diisocyanate, sealed with two coats on one side, and one on the other side using thickened latex, and then coated on the double sealed side with solution Neoprene. The 3142 fabric was sealed with one coat of thickened latex on one side and two coats on the other side. Again, the double coated side was coated with solvent Neoprene. After drying, the solvent coated faces were plied on a bias, laminated with some heat and pressure, and then cured. The composition and properties are shown below. Sample No. 2 has heavier latex coats and less solvent coat than sample No. 1. Neither sample has solvent neoprene coats on the outer surface, nor any aluminum coat.

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	1	2
Twill, wt. oz/sq.yd	2.62	2.62
Impregnation oz/sq.yd.	0.73	0.45
Coating oz/sq.yd.	2.65	2.44
Basket weave, wt. oz/sq.yd.	3.49	3.49
Coating oz/sq.yd.	3.44	2.86
Total Wt. Oz/Sq.Yd.	12.93	11.85
Total Neoprene Wt. Oz/Sq.Yd.	6.82	5.87
Permeability, $L/M^2/24$ hrs.	1.3	1.9
after 7 sec. Rotoflex	-	2.9
after 10 min. "	9.5	off scale
Fabric help ratio	3.04	2.42
Adhesion lbs/in.	11.5	8.2

Both the samples broke down more than was expected after Rotoflexing. This may be due to the high proportion of latex in the coating or to a low total coating weight.

Work on the latex coated fabrics has been stopped. Breakdown during Rotoflexing, inconsistent results, and the need for multiple coats are the reasons for this action. More work could result in an acceptable product, but is not warranted when the dry lamination system is known to work well.

5.3.2.6 Static Load Tests

Coated fabrics were subjected to static load tests and creep curves were determined. The results of the tests are summarized in Table LV.

The loads are based upon the breaking load of the uncoated, unheated fabric. This was done before the changes

due to heating were determined. Future samples will be loaded according to the breaking strength of the sample itself.

No direct comparison can be made between coated and uncoated fabrics, because no tests have been run on uncoated fabrics which were subjected to the same heat treatment as the coated ones.

In practically all cases, initial elongation under load is higher with surface coated fabrics than with those into which the coating has penetrated. The time to break appears to be longer for surface coated fabrics. As usual, Fortisan 20075 and HH cotton broke almost immediately under 60% load. For these two fabrics, the time to break is less for the coated fabric than for the uncoated one, while the reverse is true for the other fabrics.

Creep curves are shown in Figures 102-106. The coated nylon 2941 curves may show less creep than the uncoated nylon. The other curves are not much different than those of uncoated fabrics except for changes in initial elongation. This indicates that little change in creep behavior takes place due to heating of the fabric during cure of the coating. This will be checked by measuring creep of heat treated fabrics.

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TABLE LV. SUMMARY OF STATIC LOAD TESTS ON COATED FABRICS

Fabric		Initial Elongation, % 20% Load	40% Load	60% Load	Final Elongation, % 20% Load	40% Load	60% Load	Time to Break, Hrs 20% Load	40% Load	60% Load
2941	P	8.7	12.6	17.0	--	15.8	19.7	--	383	166
	S	9.2	14.0	17.1	--	--	22.4	--	--	700
15,000	P	6.4	15.7	17.1	--	--	19.8	--	--	347
	S	7.8	15.1	18.8	--	--	21.8	--	--	553
20,075	P	2.7	3.8	5.4	--	4.3	5.4	--	119	0
	S	3.6	5.1	?	--	?	?	--	0.7	0.03
RR	P	3.4	3.3	4.1	--	--	5.2	--	--	213
	S	5.3	6.4	7.0	--	--	8.0	--	--	194
HH	P	4.8	5.4	7.6	--	7.8	?	--	121	0
	S	5.4	7.0	9.6	--	9.2	?	--	318	0.5

A dash (-) indicates that the sample has not broken.
A question mark (?) indicates that no reading was obtained before the sample broke

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Creep tests were run on the standard cotton 3-ply envelope fabric. The curves are shown in Figure 107. They are very much like the curves for RR cotton except that elongation with increasing loads is higher. At 60% load, the RR ply breaks first and the load is supported for a time by the two bias plies.

As creep tests were continued it was found that the curves for the samples under 20% load did not change much. Of particular interest are creep curves of plied fabrics . These are shown in Figure 108. Nylon PNH-10 and Dacron PDH-7 are made from scoured, heat-set fabrics (basket weave plus twill). Nylon PNH_2-61 and Dacron PDH_2-60 are made from greige, heat-set fabrics. The difference between the Dacron curves is quite pronounced, with the greige fabric material showing much less creep. The two nylon curves are similar although creep of the uncoated fabrics is much different. Properties of these samples and of standard 3-ply cotton and Fortisan Y502-A12 envelope fabrics are given in Table LVI. Adhesion of plies in the PNH-10 sample is low; all other samples have ply adhesions of 5 lbs./in. or more. All samples pass permeability and 7 second Rotoflex tests.

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TABLE LVI. PROPERTIES OF PLIED ENVELOPE FABRICS

Fabric	Plies	Total Wt. Oz/Sq.Yd.	Strip Tensile Strength Lbs/In. (Warp)	Strength Wt. Ratio (Strip)	Percent Elongation 20% Static Load Initial	Percent Elongation 20% Static Load 70 days
Cotton	3	19.9	190	153	2.9	5.0
Fortisan V502-A12	3	13.9	178	205	1.5	3.7
Nylon PNH-10	3	19.1	243	204	7.8	11.4
Nylon PNH_2-61	2	11.8	203	275	5.5	10.3
Dacron PDH-7	2	15.25	266	279	5.8	9.5
Dacron PDH_2-6o	2	13.5	221	262	4.0	6.0

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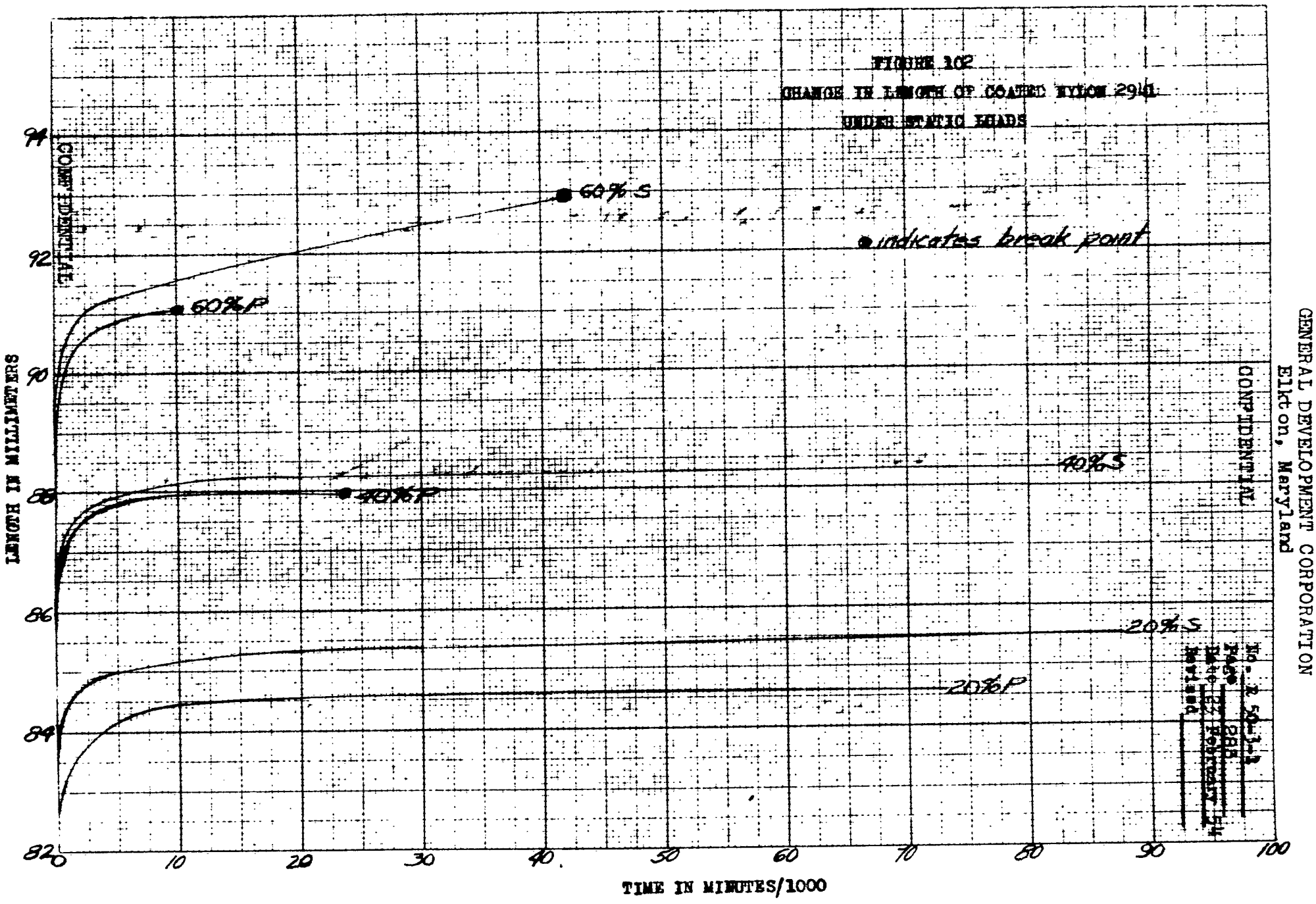

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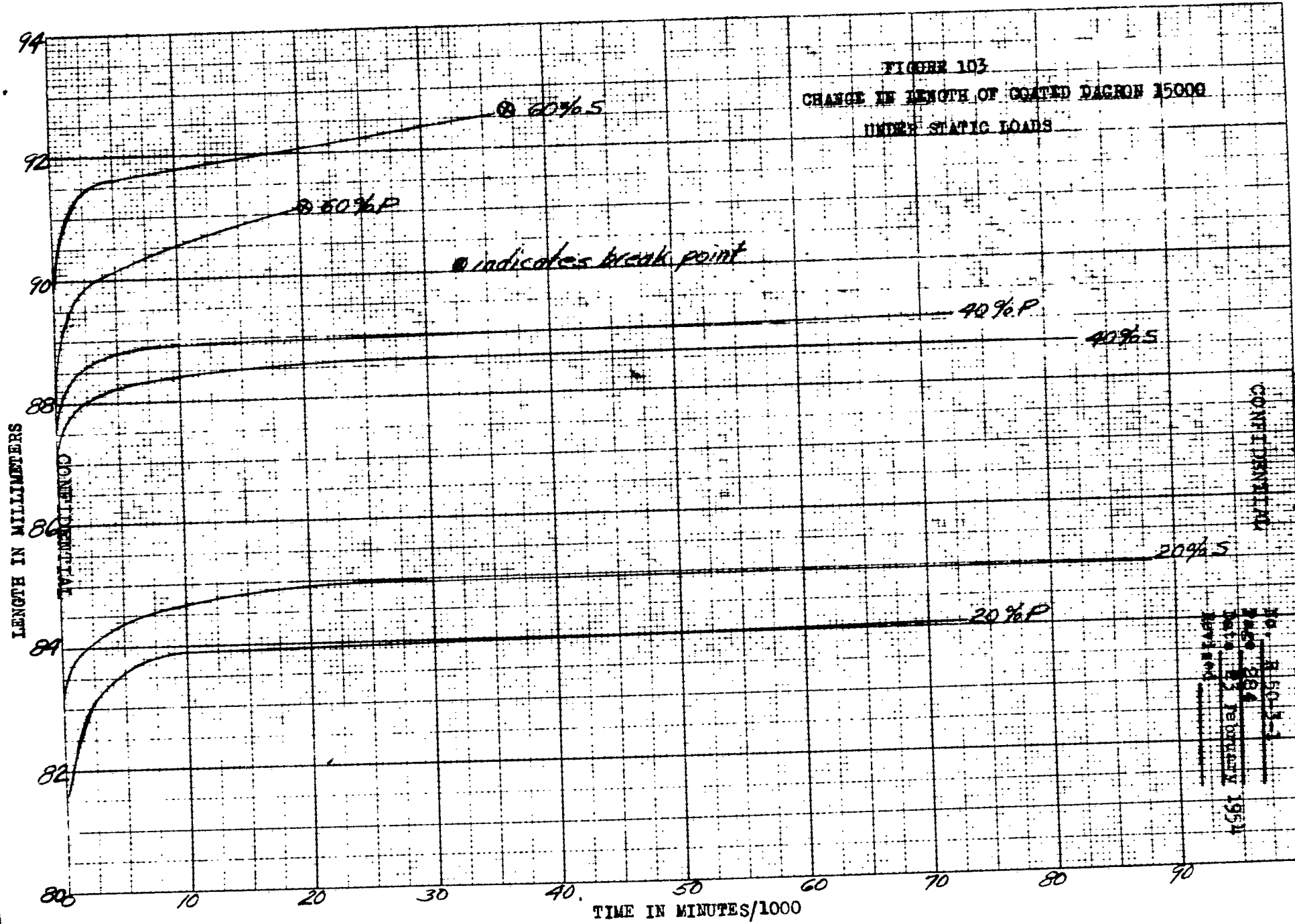

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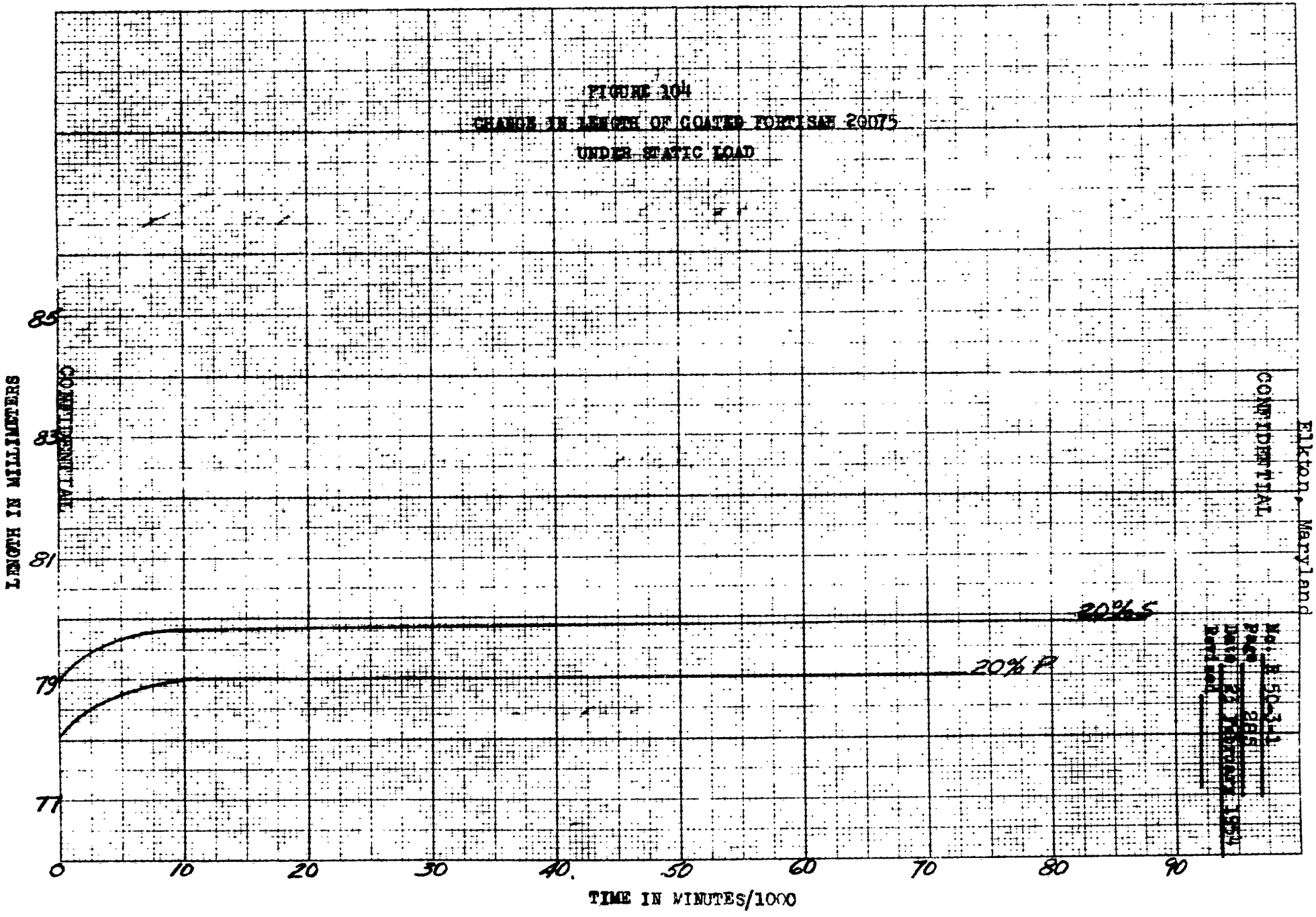

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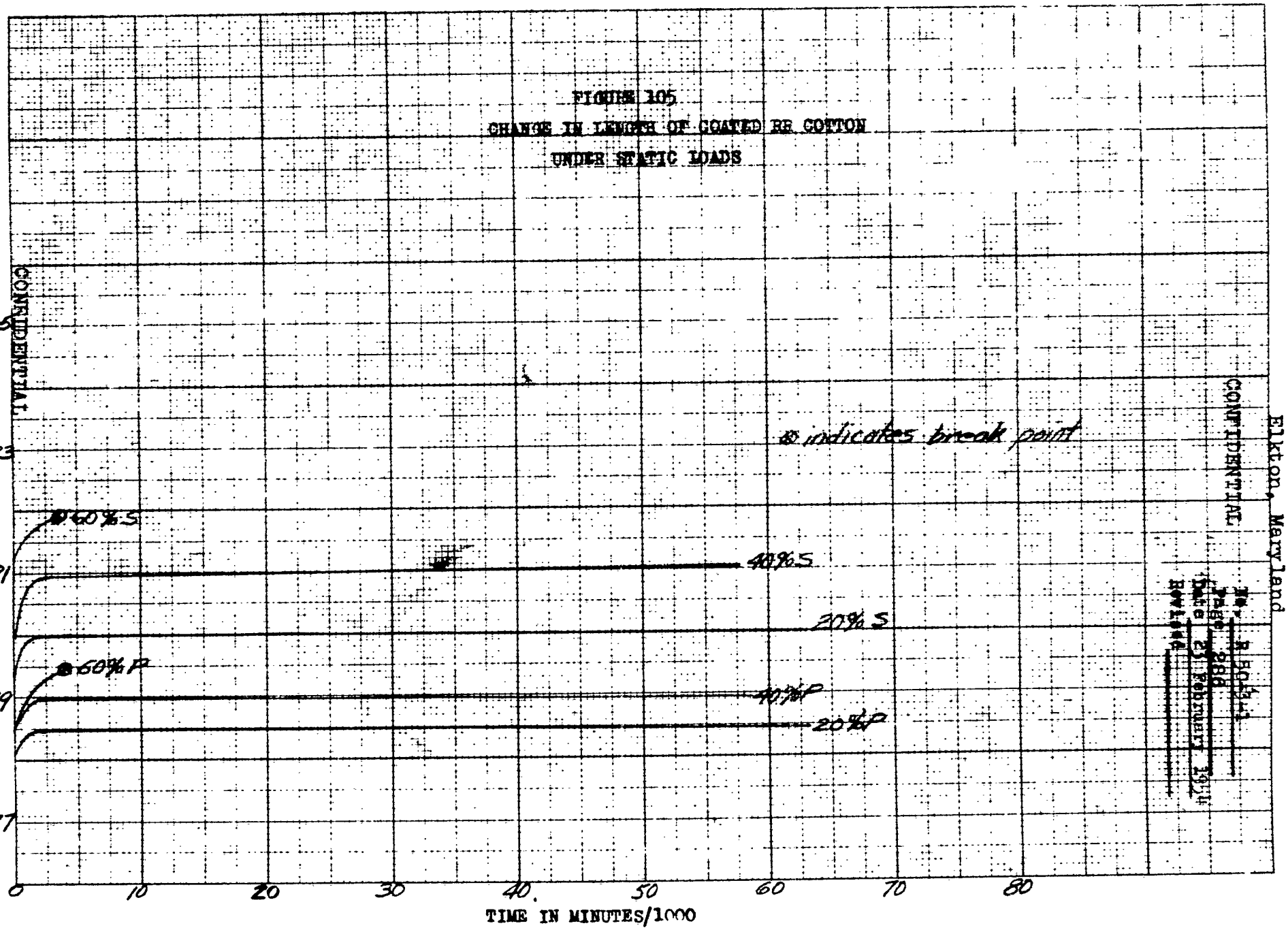
FIGURE 105
CHANGE IN LENGTH OF COATED RR COTTON
UNDER STATIC LOADS



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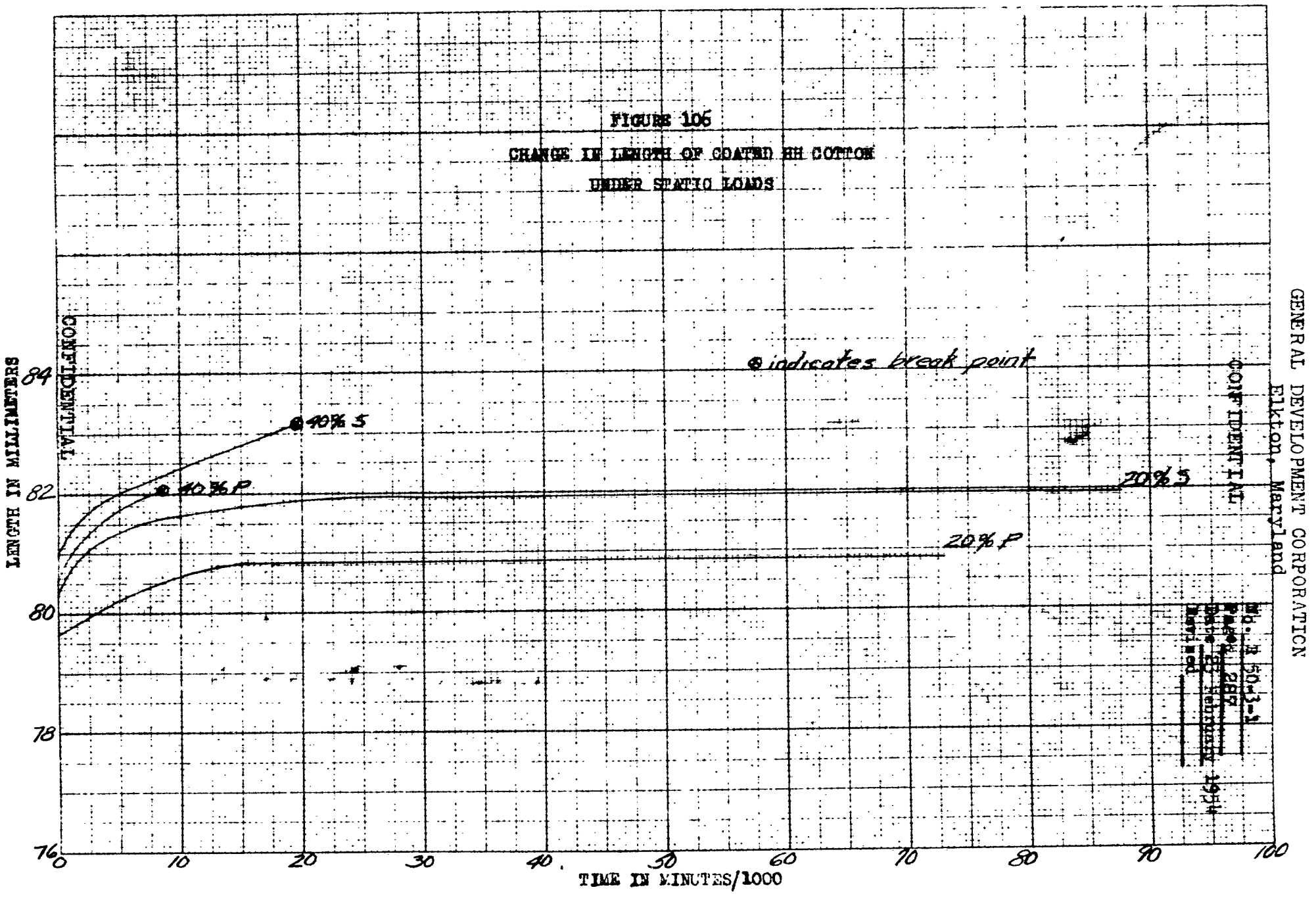

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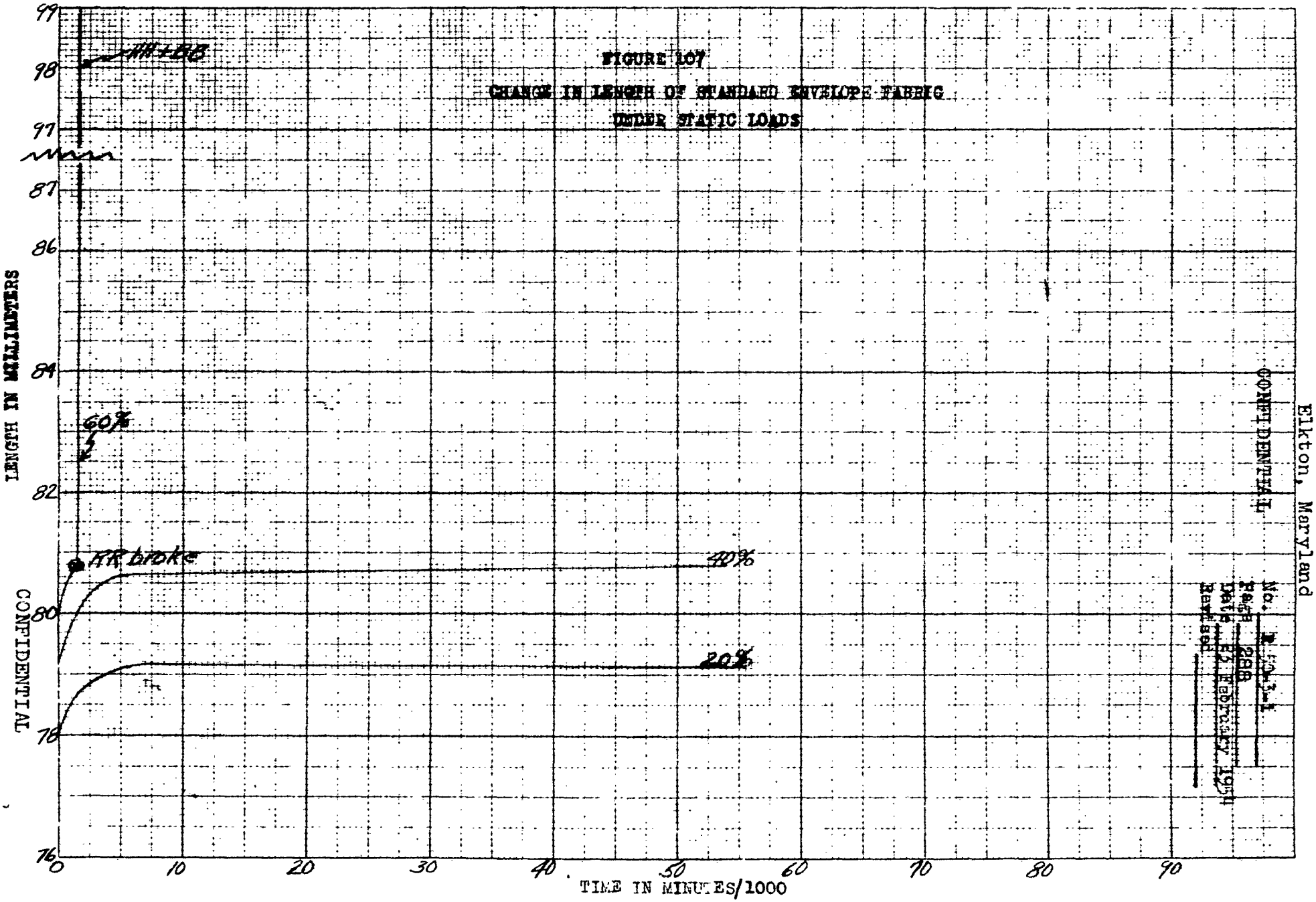

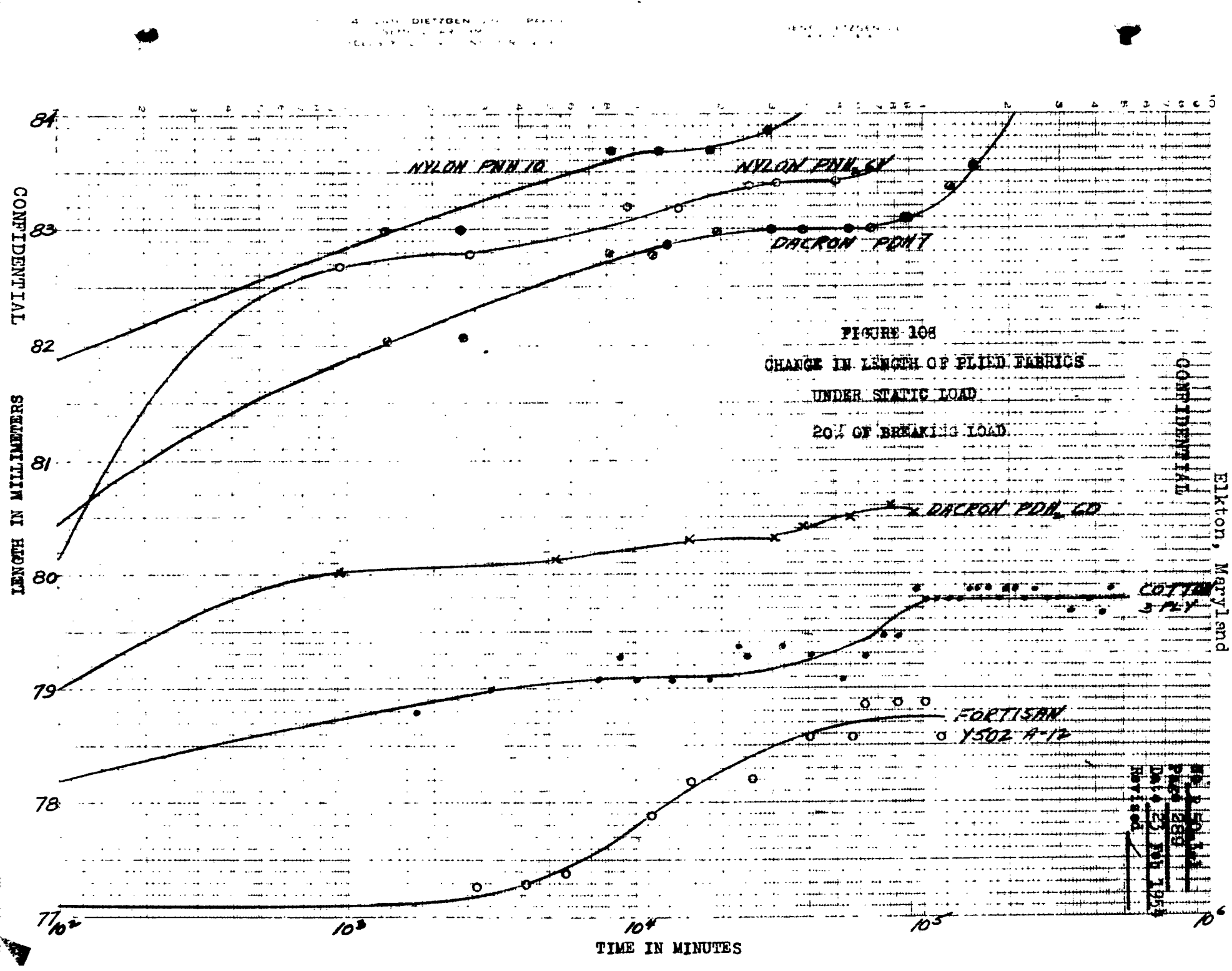

FIGURE 108

CHANGE IN LENGTH OF PLIED FABRICS

UNDER STATIC LOAD

20% OF BREAKING LOAD

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The two nylon samples and the scoured, heat-set Dacron show the most changes in elongation after 70 days. The greige, heat-set Dacron has a higher initial elongation than the cotton or Fortisan fabrics, but changes about the same amount within 70 days.

5.3.2.7 Aluminum Coatings

An air-dry aluminum coating was investigated. One that could be applied after fabrication of the envelope would eliminate the need for removing an aluminum coating at the seams.

Four different coatings were applied to a 2-ply nylon fabric. The samples, along with a 3-ply cotton envelope fabric, were placed in a Weather-Ometer. The samples were examined from time to time. The results after 7 months exposure are tabulated below:

Sample	Coating Binder	Wt of Coating Oz/Sq.Yd.	Condition after Exposure		
			Brightness	Flex Cracking	Surface Checking
1	Cycopol S-101-1	1.36	high	much	much
2	Interchemical alkyd	0.84	"	very much	very much
3	Interchemical styrene copolymer	1.03	"	some	some
4	"	0.74	"	some	very little
5	Acryloid B-72	1.33	"	slight	none
6	"	0.65	"	none	none
3-ply cotton	Neoprene	0.80	darkened	none	none

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The Acryloid B-72 coating at low film weights is as good as the standard cotton for exposure, but should have better adhesion. Some more flexible formulations have been prepared and are being tested.

An aluminum coating having a neoprene coating binder has been developed that will give a seam adhesion in excess of 10 lb/in. without requiring the buffing off of the aluminum coating. Seam tensile tests have shown that the fabric failed before the seam. The development of this aluminum coating removes the possibility of damage to the fabric during the buffing operation.

5.3.2.8 Tensile and tear strength

The tensile and tear properties of coated fabrics were determined at different coating weights and with different curing schedules. The results are summarized in Table LVI. In this table the data for uncoated fabrics is for fabrics without heat treatment.

At low coating weights, most of the changes in properties are due to changes in the fabric itself caused by the heat treatment. Cotton fabrics are an exception because coating immobilizes the staple fibers and thus increases tensile strength. Anomalous results were obtained with nylon 2941 and Fortisan 20075.

At higher coating weights the properties may be affected by those of the Neoprene itself.

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Load-elongation curves of some of the coated fabrics compared to those of uncoated fabrics with the same heat treatment are shown in Figures 109 to 112. Dacron 15000 seems to be the least affected.

The extent of cure of the coating seems to affect properties. Fabrics coated with a Neoprene composition containing twice the normal amount of accelerator, showed higher elongations and tear strength.

The results for one curing schedule are shown graphically in Figure 113 where the zero coating weight points are those of heat-treated fabric. It is apparent that much more data is needed to define the curves accurately.

Changes in tear strength with coating weight are shown in Figure 114. Tear at zero coating weight is that of the heat treated fabric. Dacron 15000 loses tear strength with increasing coating weight more rapidly than the other fabrics. There is little difference due to the method of coating.

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TABLE LVI. EFFECT OF COATING ON PHYSICAL PROPERTIES OF FABRICS

Fabric	Type	Coating No.	Wt.	Cure Time	Cure Temp.	Tensile Lbs/In.	Elongation 20%	Elongation Break	Tear Lbs
20,075	none	--	--	--	--	232	1.1	9.0	
	S	1	5.2	30 min	300°F	164	2.7	7.7	
	S	1	5.5	30	300	175	1.7	9.7	
	P	8	1.9	30	300	217	1.3	7.3	
15,000	none	--	--	--	--	184	3.0	27.3	89.9
	S	1	1.3	30	300	185	5.3	27.7	46.4
	S	1	3.3	30	300	186	4.3	25.3	35.2
	S	1	5.1	30	300	200	4.7	28.0	
	P	2	1.3	60	250	185	5.0	26.7	37.6
	P	2	1.3	30	300	190	4.0	26.0	48.0
	P	2	1.3	15	350	132	4.3	25.0	30.4
	P*	2	1.5	60	250	184	4.3	25.7	45.4
	P*	2	1.5	30	300	187	5.3	27.7	41.6
	P*	2	1.5	15	350	189	4.7	30.0	44.2
	P	8	1.8	30	300	188	4.0	28.7	38.8
15,008	none	--	--	--	--	129	0.8	22.3	51.4
	S	1	2.9	30	300	126	4.3	29.0	24.2
	P	8	2.6	30	300	132	1.3	27.3	27.2
2941	none	--	--	--	--	128	6.5	21.6	53.5
	S	1	1.7	30	300	135	7.3	26.7	29.4
	S	1	1.7	30	300	138	7.3	25.0	23.0
	S	1	2.0	30	300	127	6.7	20.3	23.4
	S-	1	6.0	30	300	110	7.3	22.0	22.6
	P	2	0.7	60	250	126	7.7	23.3	27.2
	P	2	0.7	30	300	134	7.7	26.7	24.6
	P	2	0.7	15	350	105	6.0	23.3	32.4
	P*	2	0.7	60	250	132	7.3	24.0	31.2
	P*	2	0.7	30	300	127	7.0	28.0	31.0
	P*	2	0.7	15	350	124	7.0	27.3	36.6
	P		0.7	30	300	134	7.3	31.0	
	P		0.7	30	300	134	7.0	23.3	
	P	2	0.75	30	300	130	6.7	26.7	32.4
	P	1	0.7	30	300	142	7.3	27.7	52.5
	P	8	2.8	30	300	135	6.7	26.0	25.0
2950	none	--	--	--	--	233	8.0	26.3	97.9
	P	8	5.7	30	300	233	9.3	32.7	54.4
HH	none	0	0	--	--	45	2.3	7.7	4.4
	S	1	1.1	30	300	39	2.0	6.0	3.0

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TABLE LVI. EFFECT OF COATING ON PHYSICAL PROPERTIES OF FABRICS (continued)

Fabric	Type	Coating No.	Wt.	Cure Time	Cure Temp.	Tensile Lbs/In.	Elongation 20%	Elongation Break	Tear Lbs
HH (cont)	S	1	1.2	30	300°F	40	3.3	8.0	4.5
	S	1	1.7	30	300	38	3.0	7.7	
	S	1	3.3	30	300	43	2.3	7.3	3.8
	S	1	4.8	30	300	41	2.3	5.7	3.6
	S	1	4.8	30	300	8	0.7	4.0	
	P	2	0.6	60	250	27	1.7	5.0	4.6
	P	2	0.6	30	300	45	2.0	6.7	4.6
	P	2	0.6	15	350	30	2.0	6.0	3.2
	P*	2	0.7	60	250	44	2.3	7.7	3.6
	P*	2	0.7	30	300	49	2.3	8.0	4.0
	P*	2	0.7	15	350	41	2.7	7.3	6.4
	P	8	1.5	30	300	43	2.3	7.3	5.0
	P	8	1.5	30	300	52	3.3	8.3	
	P	8	1.9	30	300	48	2.7	7.3	4.8
RR	none	0	0	--	--	136	1.5	6.0	52.6
	S	1	1.3	30	300	134	2.5	6.7	33.2
	S	1	1.5	30	300	142	2.3	6.0	35.0
	S	1	1.5	30	300	123	1.7	5.0	
	S	1	1.5	30	300	155	2.3	6.3	
	S	1	2.0	30	300	130	1.7	5.3	31.4
	S	1	2.0	30	300	145	2.0	5.7	
	S	1	3.6	30	300	147	2.3	6.7	19.4
	S	1	5.0	30	300	145	1.7	5.3	21.2
	S	1	5.7	30	300	155	3.7	8.3	
	S	1	3.6	30	300	161	2.0	5.7	
	P	1	1.1						
	S	1	4.0	30	300	170	1.7	5.3	
	P	1	1.1						
	P	1	0.6	30	300	139	1.7	6.0	48.3
	P	3	1.9	30	300	167	1.3	5.3	31.2
	P	5	2.7	30	300	144	1.7	5.7	24.3
	P	8	3.5	30	300	166	1.7	6.0	22.2
	P	8	4.4	30	300	159	2.0	5.3	
	P	8	4.4	30	300	172	2.0	5.7	

P - indicates a coating which penetrates
S - indicates a coating with little penetration
P*- indicates double the normal amount of accelerator was used

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Strip tensile strengths of many plied fabrics have been determined. As expected, there are variations due to coating weights, coating method, and differences in the fabric itself. For example, tensile strengths of 3143-3142 nylon plies vary from 170 to 213 lbs./in. for knife coated fabrics and from 215 to 246 lbs./in. for surface coated fabrics. The standard cotton envelope fabric has a strip tensile strength of 190 lbs. (average of five samples). A surface coated, two-ply nylon fabric, therefore, seems to have adequate strength. Table LVII summarizes strength data of samples which meet specification for adhesion and permeability before rotoflexing.

TABLE LVII. STRENGTH PROPERTIES OF PLIED FABRICS

Fabric	Wt. Oz/Sq.Yd.	Strip Tensile Strength Lbs/In.	Strength-Weight Ratio
Standard 3-ply cotton	20.0	190	152
3-ply nylon NH-11	20.0*	245	196
2-ply nylon NH-16	13.8*	237	275
" " NH-19	12.4*	235	303

*Does not include aluminum coat

Strength-weight ratios of the nylon fabrics are much higher than for cotton fabrics. The nylon fabrics still must pass cylinder burst tests, rotoflex tests, and crease tests, before they can be declared suitable for use in airship envelope fabrics.

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The coated samples which had been exposed in the Weather-Ometer for 7 months were tested for tensile strength.

Sample No.	Tensile Strength, Lbs/In. Original	After Exposure	% Loss
1	237	222	6.3
2	237	203	14.3
3	237	203	14.3
4	237	206	13.1
5	237	230	3.0
6	237	220	7.2
3-ply cotton	190	113	40.5

The nylon fabrics lost little strength in comparison to the cotton fabric. The dacron fabrics should be as good or better.

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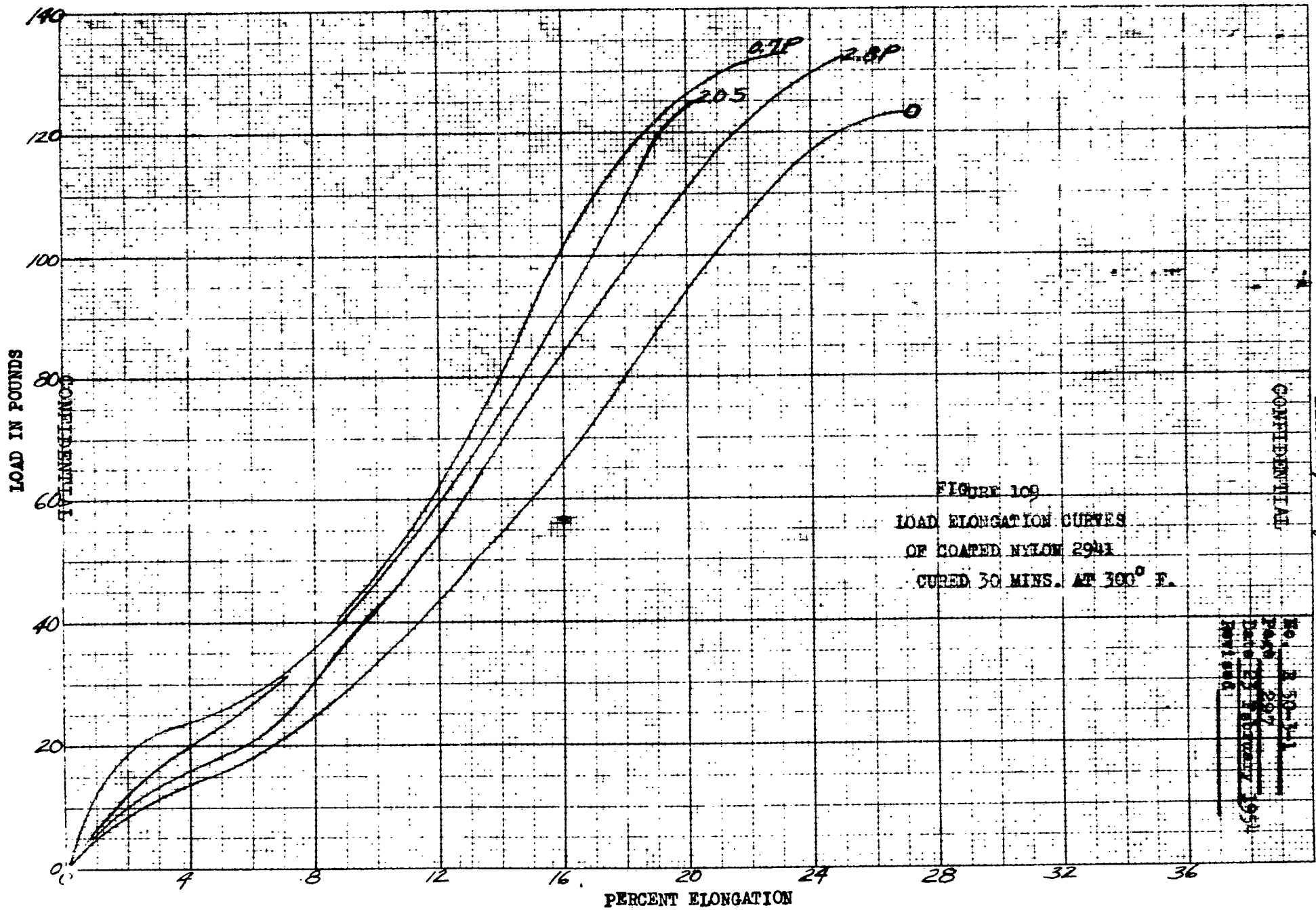

FIGURE 109
LOAD ELONGATION CURVES
OF COATED NYLON 2941
CURED 30 MINS. AT 300° F.

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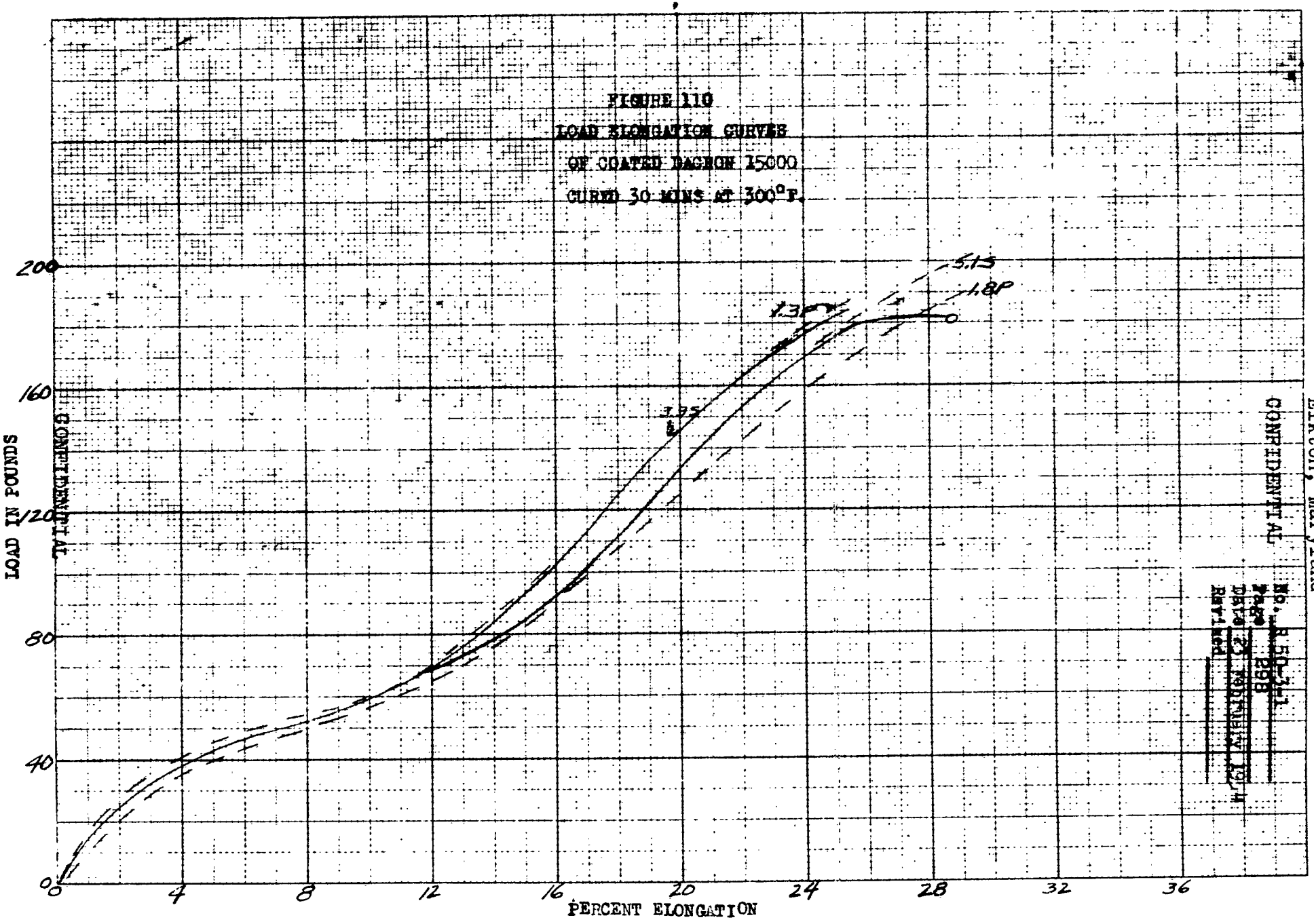

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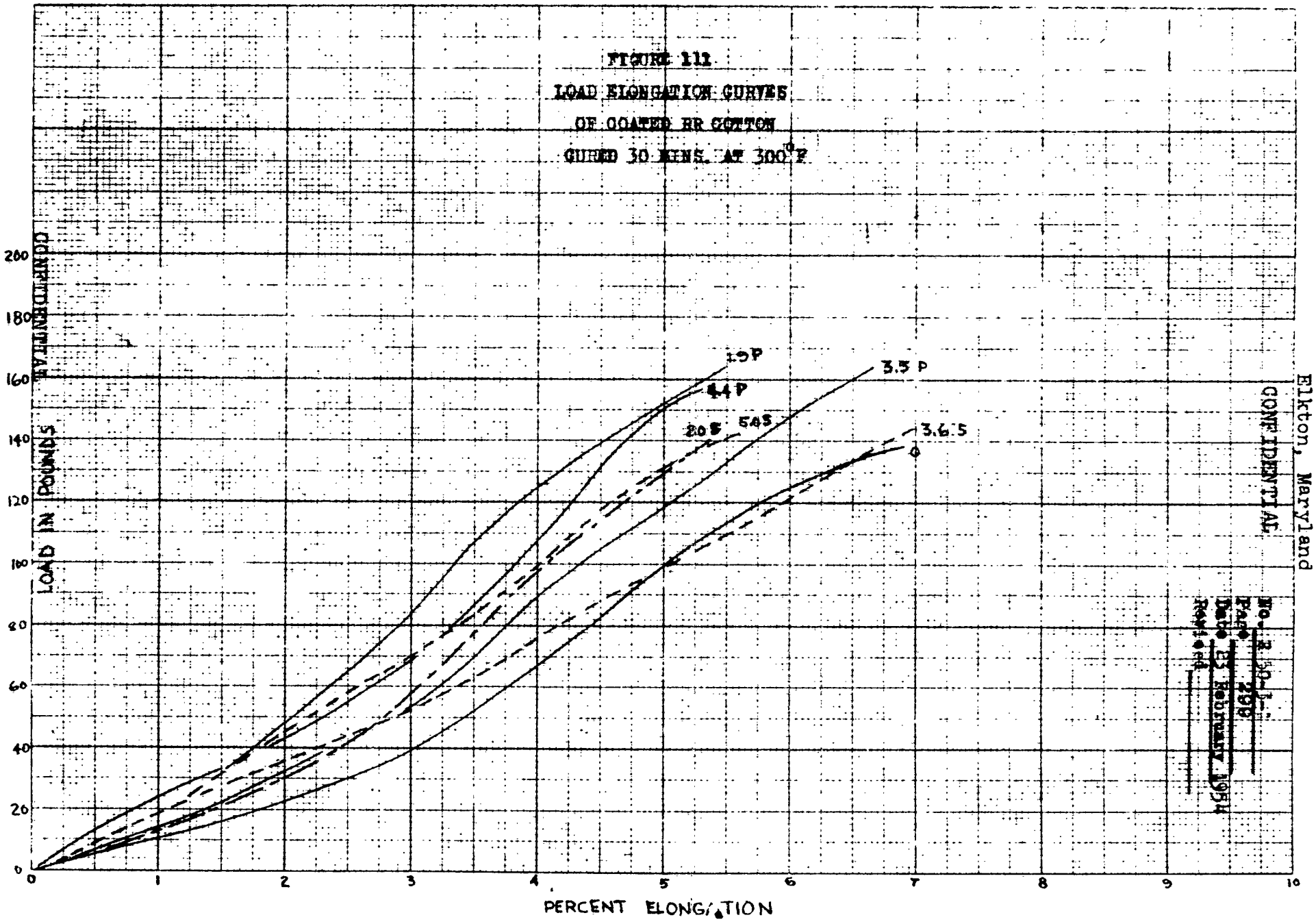

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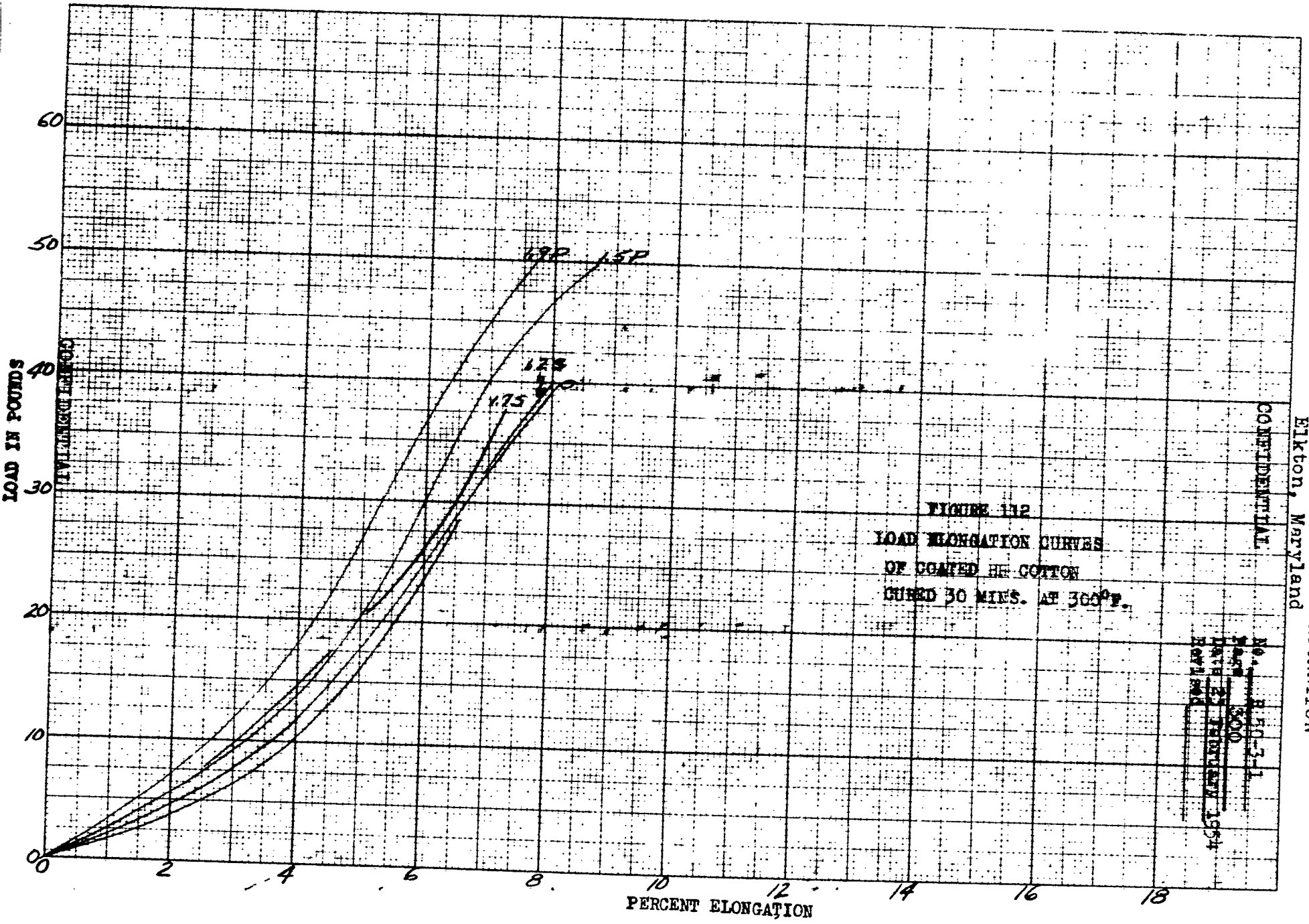

FIGURE 112
LOAD ELONGATION CURVES
OF COATED HE COTTON
CURED 30 MINS. AT 300°F.

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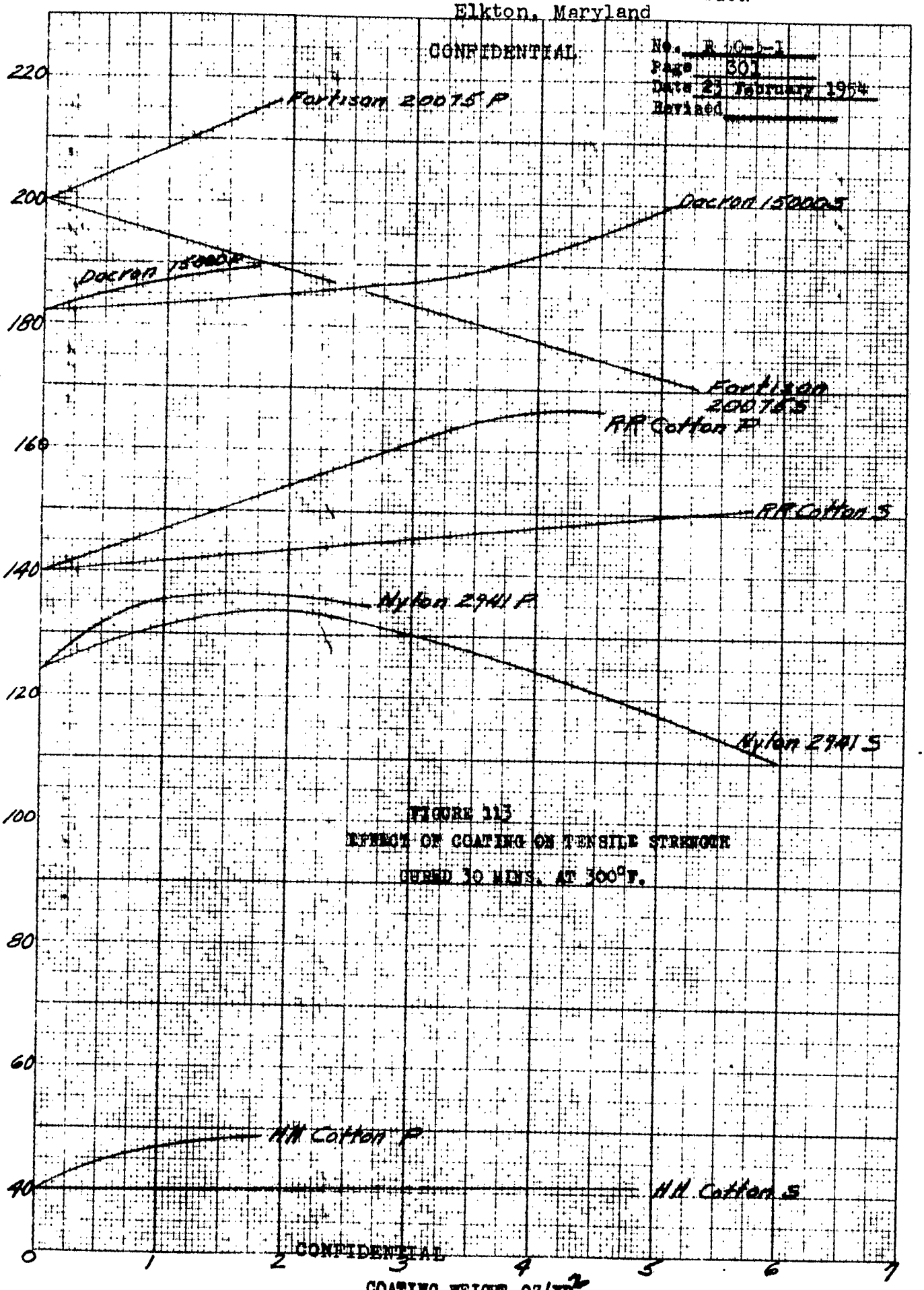

FIGURE 113
EFFECT OF COATING ON TENSILE STRENGTH
CURED 30 MINS. AT 300°F.

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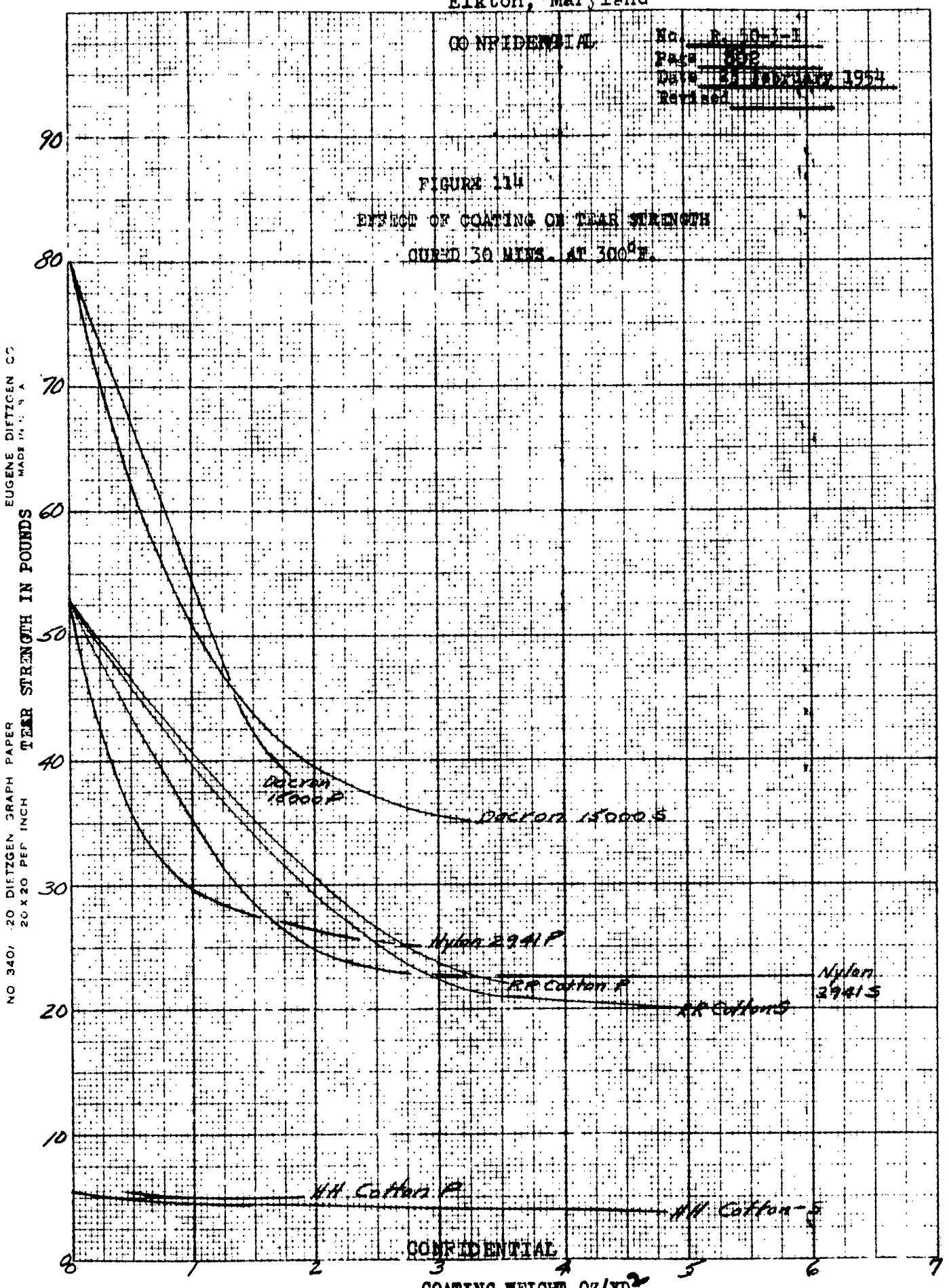

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5.3.2.9 Dacron-nylon combinations

Attempts were made to replace the Dacron twill of the Dacron plied fabric with a lighter weight nylon twill having at least the same strength. Nylon twills which had been subjected to various treatments, and which therefore varied in the degree of shrinkage, were used. In all cases excessive wrinkling occurred, and the plied fabrics curled. The amount of shrinkage of the two fabrics must be matched fairly closely to obtain a smooth plied product.

5.3.2.10 Pilot plant runs

The first pilot plant runs were made by coating treated paper with Neoprene solution. The fabric, which was pretreated with an MDI - Neoprene prime coat, was laminated to the film at various stages of drying.

Thirty-five small samples were prepared in this manner. Nylon and Dacron basket weave and twill fabrics was used. Variables studied were coating weight, temperature, drying time, and pressure. Some of the samples showed little or no adhesion of fabric to Neoprene. This occurred when the film was too dry.

Eleven plied samples were prepared using a basket weave fabric and a bias twill in each case. One ply was discarded because of excessive bubble formation in the coating. The composition and test results are

given in Table LVIII.

All the adhesion results and initial permeabilities fall within present specifications of 5 lbs. per inch and 8 $L/M^2/24$ hrs. Permeabilities after Rotoflexing for one minute have changed considerably in some cases. It is probably that little change would take place after 7 second of Rotoflexing, so these samples would pass present specifications. Details of further work on effects of Rotoflexing are given in a later section. These will lead to modification of the present Rotoflex testing procedure.

The second pilot plant run was made with fewer variations in conditions using larger pieces of fabric. The samples were back coated before stripping. This caused the formation of blisters which are undesirable. Eleven samples were prepared. From these, two plied Dacron fabrics and two plied nylon fabrics were made. Their composition and properties are listed in Table LIX. All four samples pass tensile, adhesion, and initial permeability specifications. The sample with the lowest total amount of Neoprene shows the greatest breakdown in permeability. Elongation at 20% load is slightly lower for the Dacron samples (3.0% vs. 3.6% average). These values compare favorably with the elongation at 20% load of the 3 ply cotton envelope material which is 2.0%.

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Cylinder burst tests were made with the above samples. One Dacron fabric failed at the seam. The other Dacron fabric was not taken to bursting pressure, because the paper strip, used to measure elongation, broke. The results are summarized in Table LX. Rate of application of pressure was about the same for all samples, but no relation was established with Scott tensile rates. The elongation figures at 20% load are of interest because the nylon fabrics and the cotton fabric have values which are almost the same. Elongation values from the cylinder test are higher than from the strip test in both cases.

TABLE LVIII. COMPOSITION AND PROPERTIES OF PLIED FABRICS - PILOT PLANT RUN #1

Fabric	Wt. of Neoprene Basket Back	Basket Face	Twill Back	Twill Face	Oz/Sq.Yd Total	Tensile Strength Lbs/In.	%Elongation Ult.	%Elongation 20% Load	Permeability $L/M^2/24$ Hrs. Initial	Permeability 1 Min. R*	Adhesion Lbs/In.	Total Wt. Cured Fabric Oz/Sq.Yd.
Nylon	1.50	1.85	1.10	2.75	7.22	244	33.3	5.0	1.2	18.4	8.7	14.1
"	1.55	1.20	1.20	2.18	6.13	234	29.0	5.0	6.4	off scale	9.8	13.0
"	1.20	2.30	0.80	2.95	7.25	230	29.3	4.7	5.6	off scale	8.7	14.1
"	1.20	4.30	1.00	2.50	9.00	237	40.0	4.0	0.7	1.0	8.0	15.8
Dacron	0.95	2.00	1.15	2.10	6.20	242	35.7	4.0	1.2	11.0	5.7	15.45
"	0.50	1.80	1.40	2.63	6.33	251	34.0	2.7	3.6	64.0	8.5	15.6
"	1.05	1.75	1.65	1.82	6.27	266	35.0	3.3	3.5	34.0	5.0	15.5
"	0.65	1.85	1.50	2.77	7.07	226	34.0	4.0	1.3	3.1	7.0	16.3
"	0.80	2.75	1.30	2.90	7.75	259	43.0	2.3	2.4	11.1	8.8	17.0
"	1.00	1.52	0.95	2.80	6.27	243	39.7	2.3	3.9	off scale	6.0	15.5

* One minute Rotoflexing in each of four directions using 880 g. load

Permeability was dependent on how well the neoprene stripped off of the Holland cloth

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TABLE LIX. COMPOSITION AND PROPERTIES OF PLIED

NYLON AND DACRON FABRICS - PILOT PLANT

RUN #2

Fabric	Weight of Neoprene Between Plies	Oz/Sq.Yd. Total	Total Wt. of Fabric Oz/Sq.Yd.	Tensile Strength Lbs/In.	% Elongation Ult.	% Elongation 20% Load	Adhesion Lbs/In.	Permeability $L/M^2/24$ hrs. Initial	Permeability $L/M^2/24$ hrs. 1 MinR*
Nylon	3.60	6.90	13.75	241	28.3	3.3	9.1	3.8	20.0
"	6.10	9.65	16.5	250	30.0	4.0	10.8	2.0	5.0
Dacron	5.20	8.30	17.55	256	32.0	3.3	8.0	2.1	6.6
"	5.00	8.35	17.6	256	32.0	2.7	9.0	2.0	2.0

* 880 gm wt. used on Rotoflex

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TABLE LX. CYLINDER BURST TEST DATA

Fabric	Tensile Strength, Lbs/In. Scott Strip	Cylinder Burst	% Elongation Ult.	% Elongation 20% Load	Total Wt. Oz/Sq.Yd.
Dacron	256	--	--	--	17.55
Dacron	256	--	--	--	17.6
Nylon	241	168.5	21.7	5.1	13.75
Nylon	250	219.0	15.8	4.2	16.5
Standard Cotton	190	198.7	8.7	4.5	19.9

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5.3.2.11 Crease tests

It was decided to test the two-ply nylon and two-ply dacron fabrics on a crease tester similar to that used by the Goodyear Aircraft Corporation. A three ply cotton envelope fabric was also tested at the same time in order that the data could be compared.

The following samples were creased in such a manner so that the crease was in the warp direction of the straight ply fabric. The crease was in the center of the test sample. The results are as follows:

Sample No.	Tensile Lbs/In.	% Elongation at full load	Remarks
Cotton - 3 ply (Warp) (Figures P1 & P2 in Appendix I)			
1	185	4.0	RR broken at crease
2	184	4.0	RR broken at crease
Average	184.5	4.0	
	194	5.3	Averages before creasing
	4.9		% loss in strength

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Sample No.	Tensile Lb/In.	% Elongation at full load	Remarks
Run #9 Dacron (warp) (Figures P3 & P4 in Appendix I)			
1	205	23.3	Basket weave not broken on crease
2	216	22.7	Basket weave not broken on crease
Average	210.5	23.0	
	211.2	25.1	Averages before creasing
	0.33		% loss in strength
Run #7 Nylon (warp) (Figures P5 & P6 in Appendix I)			
1	188	22.0	Basket weave not broken on crease
2	199	22.7	Basket weave not broken on crease
Average	190.0	21.1	
	190.0	21.1	Averages before creasing
	0		% loss

The results of the samples that were creased in the fill direction of the straight ply is as follows: (crease in center of test sample).

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Sample	Tensile Lbs/In.	% Elongation at full load	Remarks
Cotton 3 ply (fill) (Figures P7 & P8 in Appendix I)			
1	148	7.7	RR broken at crease
2	147	8.3	RR broken at crease
Average	147.5	8.3	
	178	7.5	Average before crease
	17.1		% loss in strength
Run #9 Dacron (fill) (Figures P9 & P10 in Appendix I)			
1	222	28.0	Basket weave not broken at crease
2	223	28.7	Basket weave not broken at crease
Average	222.5	28.4	
	218.0	27.2	Average before crease
	0.0		% loss in strength
Run #7 Nylon (fill) (Figures P11 & P12 in Appendix I)			
1	193	20.7	Basket weave broken at crease
2	200	20.7	Basket weave broken at crease
Average	196.5	20.7	
	191	23.9	Average before crease
	0		% loss in strength

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In order to determine the effect of a bias crease, the samples on the crease tester were folded so that the crease was approximately at a 45° angle from the straight ply. The samples were run so that the warp direction of the straight ply was parallel to the edge of the endless belt. The crease was running at 45° across the center of the test specimen.

Sample	Tensile Lbs/In	% Elongation at full load	Remarks
Cotton 3 ply (Figures P13 & P14 Appendix I)			
1	110	5.0	Break started on crease of H.H. RR also torn on crease slightly.
2	112	5.7	Break on crease. RR again torn slightly on crease edges
Warp	122.2	12.7	Average before crease
Fill	125.6	7.4	Average before crease
Run #9 Dacron (Figures P15 & P16 Appendix I)			
1	122	28.0	Broken away from crease
2	133	26.7	Crease partially broken. Major break just above crease
warp	138.2	28.0	Average before crease
Fill	135.3	26.3	Average before crease

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Sample	Tensile Lbs/in.	%Elongation at full load	Remarks
Run #7, Nylon (Figures P17 & P18 Appendix I)			
1	122	16.3	Break start on crease
2	136	16.3	Break across center of crease
warp	140.8	18.9	Average before crease
fill	135.2	17.7	Average before crease

Photographs of the crease test samples are shown in Appendix I.

Conclusions

The base fabrics, methods of coating and plying operations have been developed to produce an airship envelope fabric which is lighter in weight and stronger than the fabric now in use, thus having a better strength-weight ratio. Thedacron fabric also has a higher tear strength, better resistance to outdoor exposure, least loss in tensile under load, good adhesion between plies, and low permeability before and after rotoflex.

A comparison of the nylon and dacron fabrics, developed under this contract, with cotton is shown below. The tests were performed at ambient conditions

	3 Ply cotton	Nylon	Dacron
Weight (oz/sq.yd.)	19.5 ± 0.5	12.0 ± 0.5	13.5 ± 0.5
Tensile strength (lbs/In)	190 x	190x101	211x218
Tear strength (lbs)	93 x	124x132	139x150
Adhesion between plies (lb/in.)	>10	>10	>10
Permeability (l/M^2/24 hrs)			
initial	<3	<3	<3
after rotoflex	<3	<3	<3
Strength-weight ratio	152	250	237
Yards to break* (tensile strength)	5610	9120	9003
Creep	least	most	med.
Loss in tensile under load	most	med.	least
Weather resistance	lowest	med.	best
Cylinder burst strength	260	312	349

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	3 ply cotton	Nylon	Dacron
Strength-weight ratio based on cylinder burst test	213	416	413
Yards to break (cyl. burst test)	6300	14,900	14,900

* Minimum length of material one yard wide which will break when suspended by one end.

Long time tests, such as creep and exposure in a Weather-o-meter, are being continued. Since cotton and fortisan fabric have been used in actual service, cotton being representative of a successful fabric, it was decided that they should be use as control fabrics in laboratory tests. In this way, an attempt could be made to interpret the data obtained in the laboratory tests in terms of actual service data. Tests perf ed in accordance with specification LTA-14a (at room conditio showed that the fabric developed under this contract were superior to those currently used.

It is believed that as more experience is gained, refine ments in the preparation and construction of this envelope fabric are possible, which will result in a further lowering in weight.

The nylon envelope fabric is ligher in weight than the dacron fabric. More data on creep is necessary to determine if this material can be used in an envelope.

A decrease in weight in the dacron envelope fabric can

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Recommendations

It is recommended that in order to fully realize the objectives of this contract and to more completely test in the laboratory the fabrics under consideration, that the scope of this program be broadened by the inclusion of:

1. accelerated tests by varying (a) temperatures from -65°F to 160°F, (b) relative humidity up to 95%, and (c) exposure tests. This would accelerate the effects of the deterioration of the fabric properties in order that it can be evaluated as a possible envelope fabric before it is actually used in the construction of an envelope.
2. more exhaustive tests on the neoprene base aluminum coating that does not require buffing at the seams. Preliminary tests performed to date indicate (as shown in Section 4.2.7) that the coating is possible and it eliminates damage to the fabric during the buffing operation used with current aluminum coatings.
3. testing coating materials other than or in conjunction with neoprene in order to improve permeability, improve weathering qualities, and attain a reduction in weight.

4. effects of oil, gasoline, roofing tars, mildew and acids on the envelope fabric. This would determine if any deterioration of the coated fabric occurs when exposed to these substances.

If these proposed tests bear out all indications to date, the superiority of a two-ply dacron envelope fabric will be established.

It is further recommended that

1. to try to develop a ballonet fabric with a total weight of approximately 4.5 oz/sq.yd. Since the present fabric weighs 6.6 oz/sq.yd., this would result in a weight saving.
2. to thoroughly investigate the three yarn cloth construction with respect to
   (a) methods of producing the cloth, (b) technique employed for coating and plying the cloth to reduce the permeability (c) its advantages for use in an airship envelope. (The use of a single three yarn cloth would eliminate the need for a bias ply).
3. the dacron two ply fabric made in Plant Run #9 be subjected to the tests outlined in the first paragraph of this section (recommendations) This would compare a dacron envelope fabric made on production equipment with a cotton fabric made on production

equipment. If the creep of the nylon fabric can be successfully controlled by the techniques currently being investigated then the nylon fabric should be subjected to the series of tests also. A comparison of the cotton 3 ply, nylon 2 ply and dacron 2 ply fabrics is shown in the conclusions. These tests, however, were performed at ambient conditions and as pointed out above the exposure tests would accelerate any deterioration of properties that would result from actual long time service.

After the plant run fabrics were subjected to a series of tests in the Weather-o-meter, it was felt that an increase in the outside coating of 0.5 oz/sq.yd. would give added protection against the elements. Since this is desirable future dacron fabrics would weigh 14.0 $\pm$.5 oz. per sq. yd. After reviewing the dacron fabric developed under this contract, it was felt that it would be more desirable to replace the twill by a smoother weave fabric having the same strength and approximately the same weight as the twill. The smoother weave would allow a greater portion of the outside coating to be on top of the fabric and thus give the cloth more protection against the effects of the sun's rays.

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APPENDIX I

Page 318

Figure P1 R 50-3-1

3 Ply cotton envelope fabric
Crease in warp direction of straight ply fabric
Sample No. 1
a = crease
b = failure in fabric

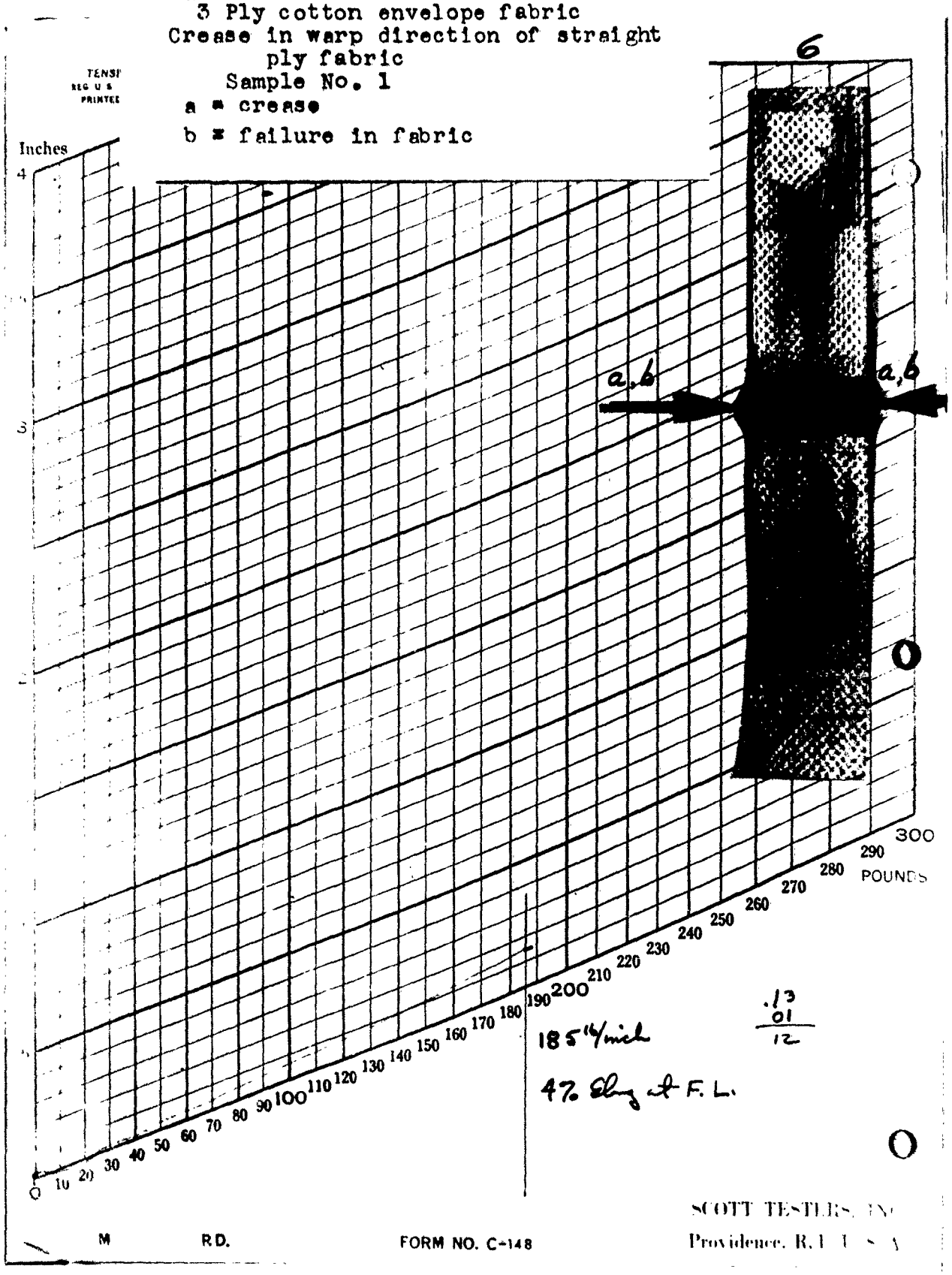

Figure P2 R 50-3-1

3 Ply Cotton Envelope Fabric

Sample No. 2

Crease in warp direction of straight ply.

a = crease

b = failure in fabric

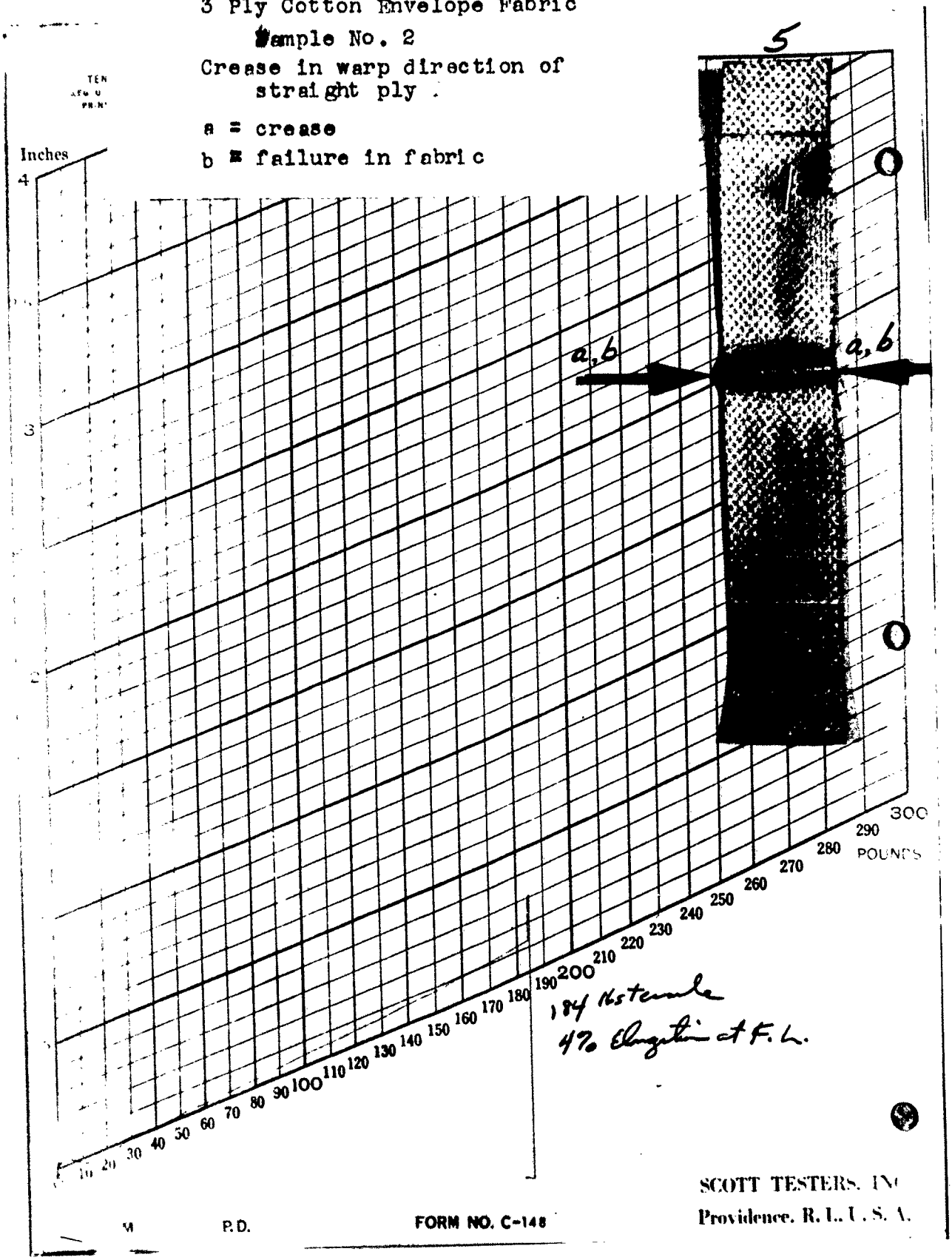

Figure P3

Plant run #9 - Dacron 2 ply

Sample No. 1

Crease in warp direction of straight ply

a = crease

b = failure in fabric

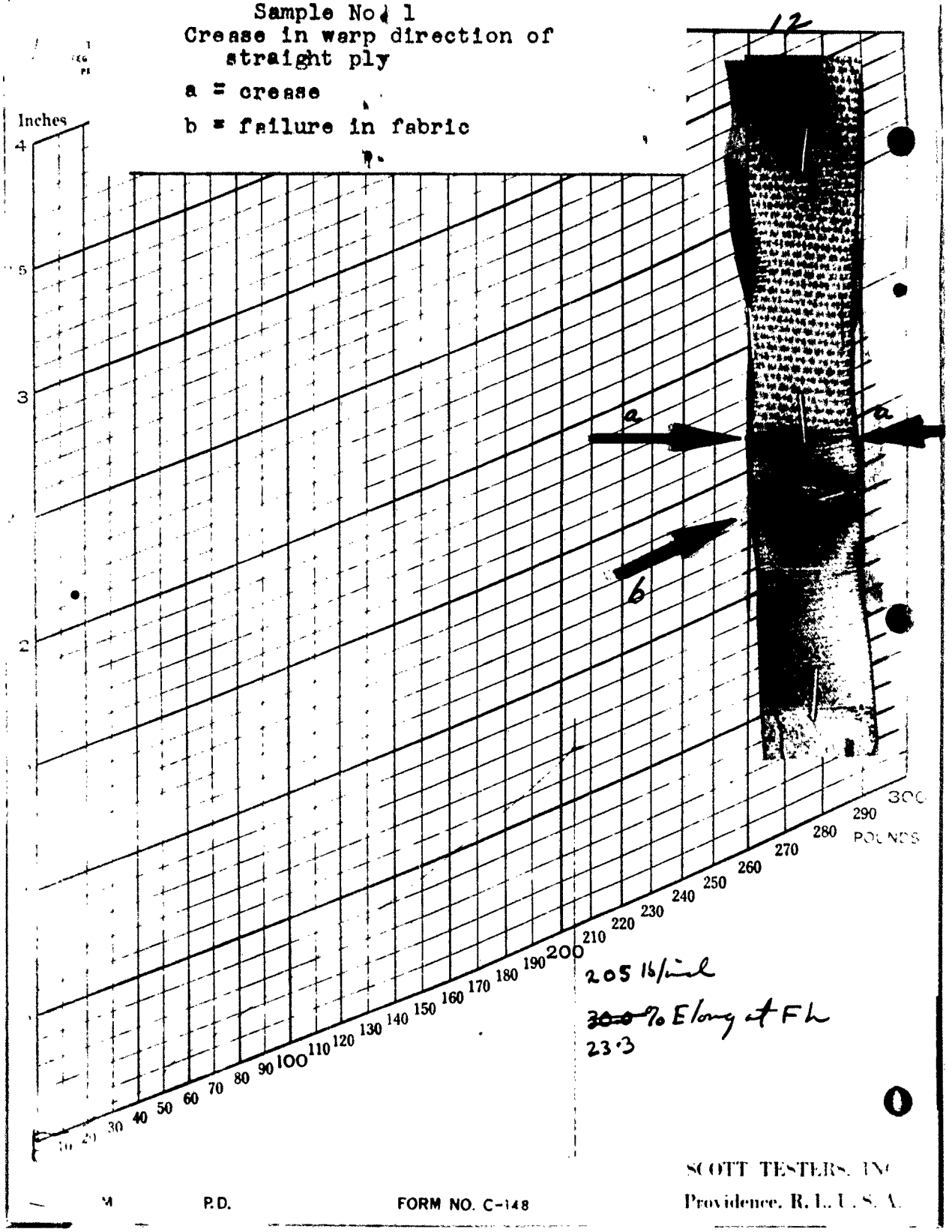

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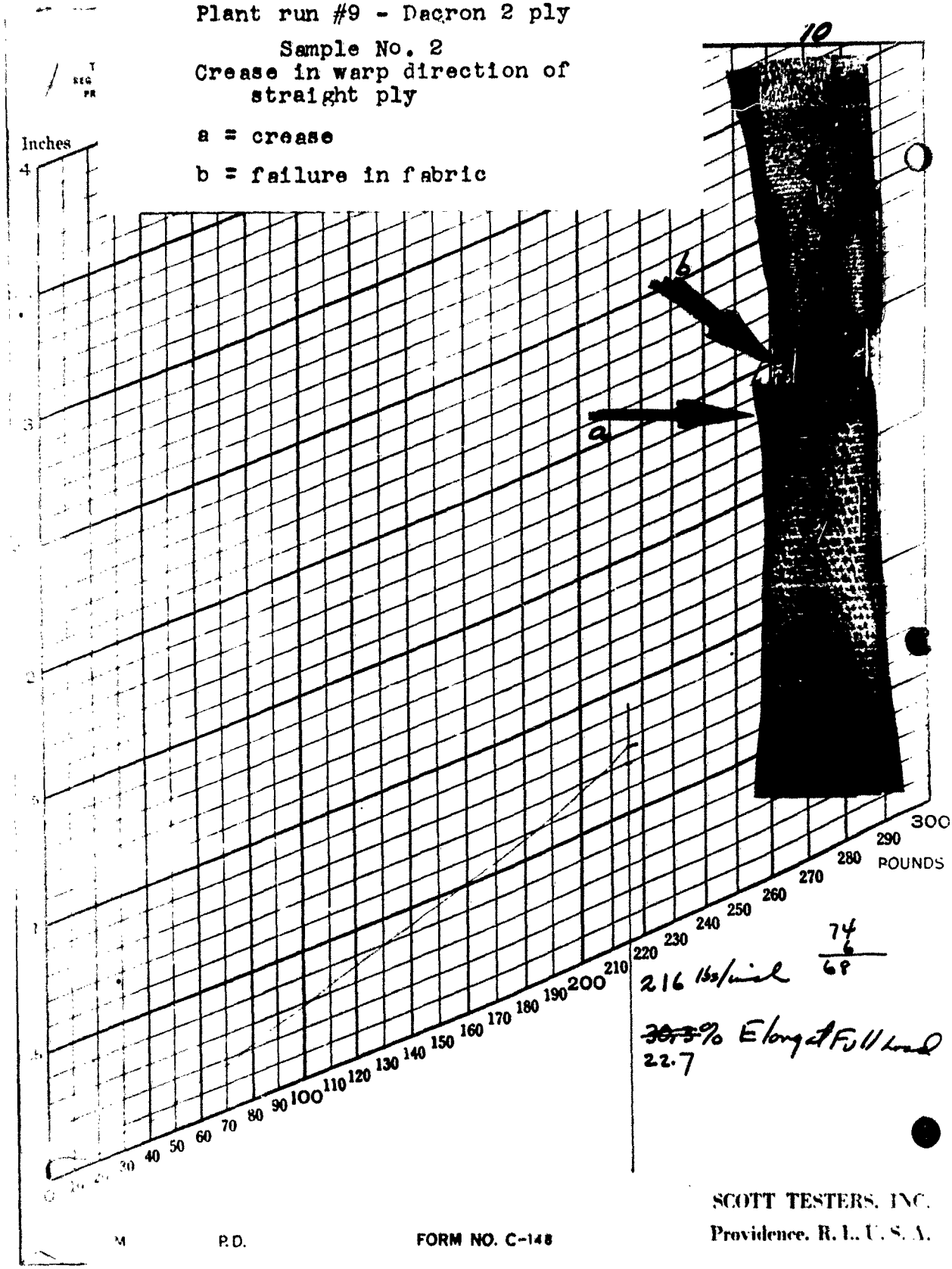
Figure P4

Plant run #9 - Dacron 2 ply

Sample No. 2
Crease in warp direction of straight ply

a = crease

b = failure in fabric



74
6
68

216 lbs/inch

~~30.5~~% Elong at Full Load
22.7

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Figure P5

50-3-1
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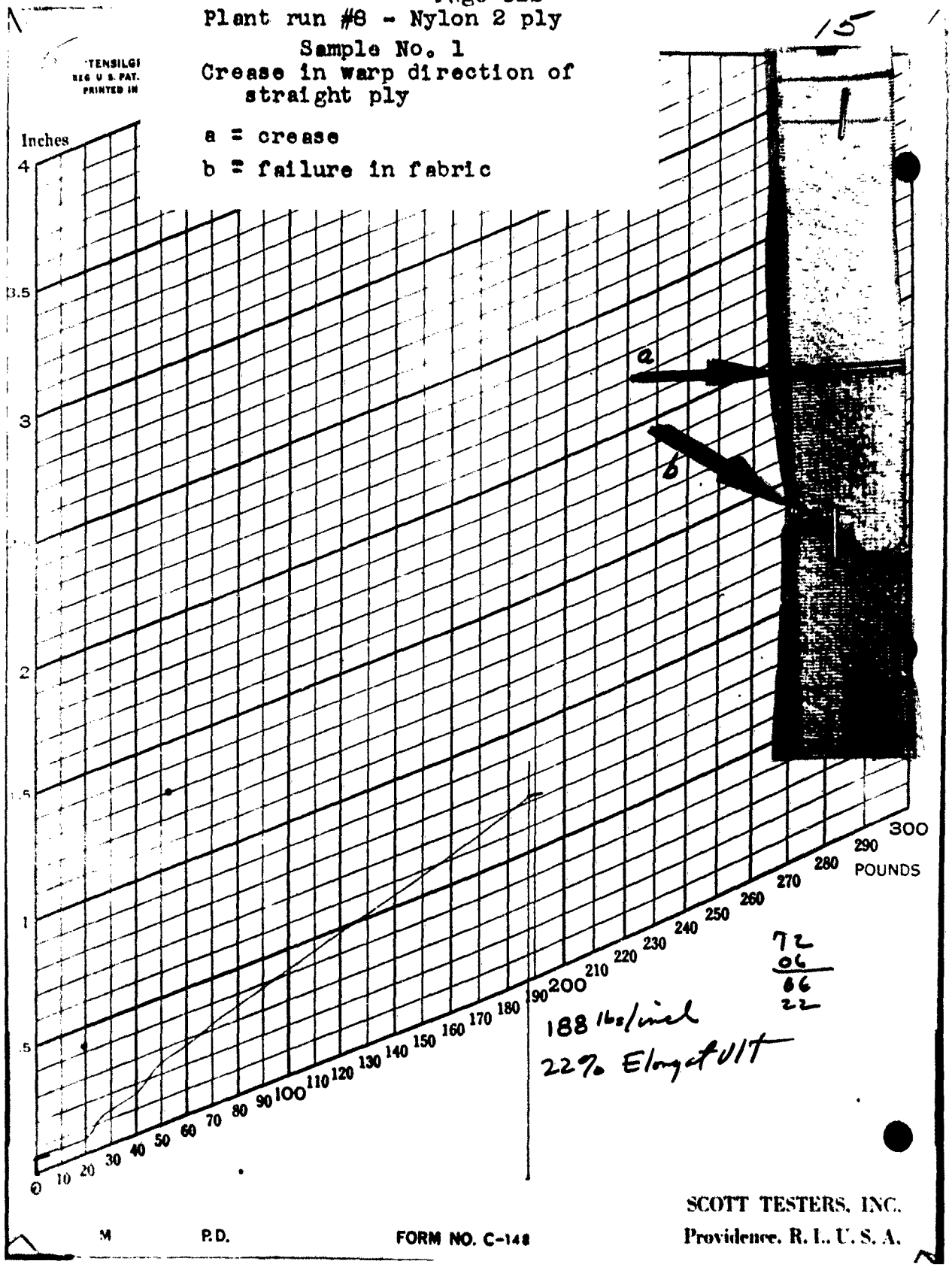
Plant run #8 - Nylon 2 ply
Sample No. 1
Crease in warp direction of straight ply

a = crease
b = failure in fabric



72
06
66
22

188 lbs/inch
22% Elong at Ult

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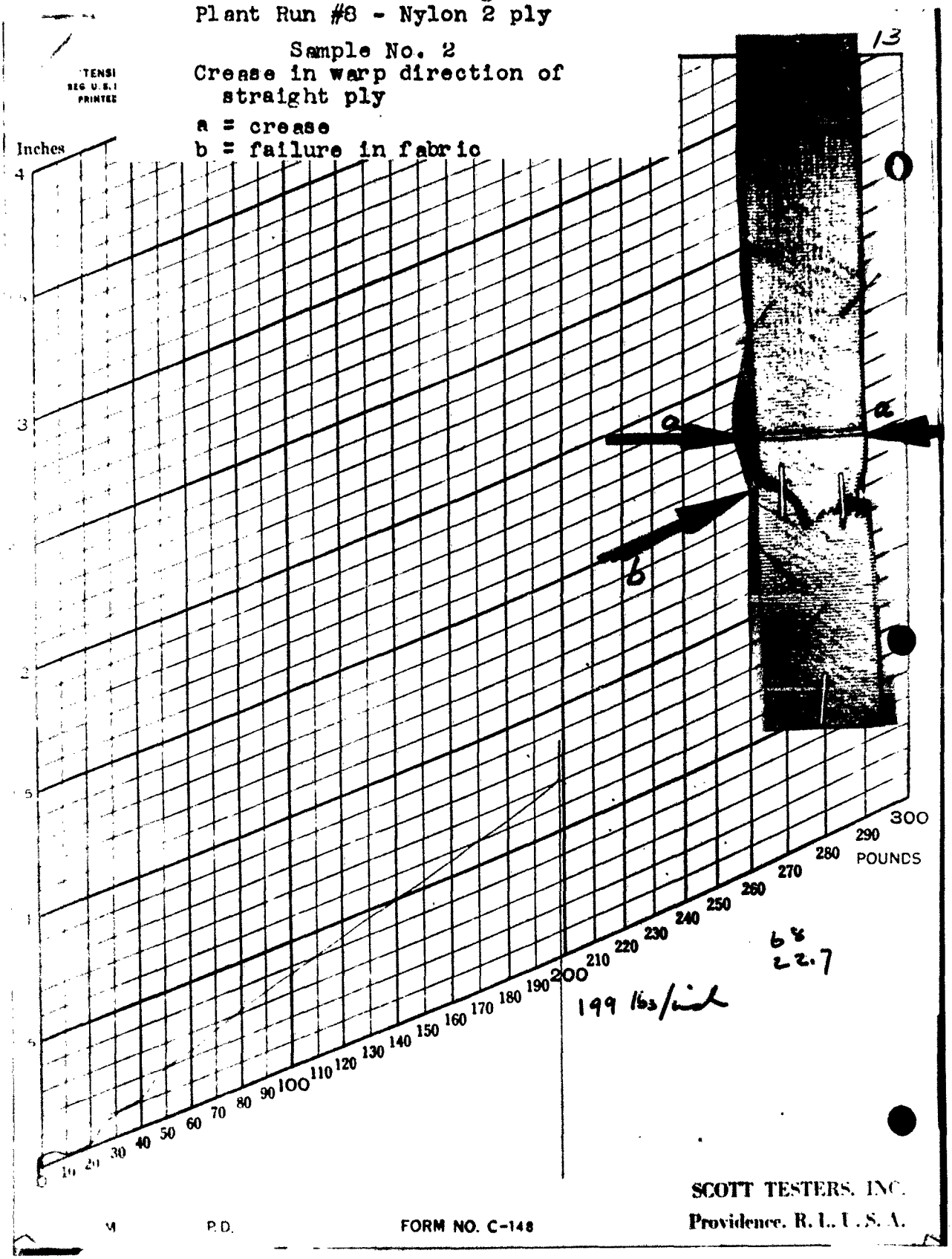
Figure P6

Plant Run #8 - Nylon 2 ply

Sample No. 2
Crease in warp direction of straight ply

a = crease
b = failure in fabric



3 Ply Cotton Envelope Fabric

Sample No. 1
Crease in fill direction of straight ply

a = crease
b = failure in fabric

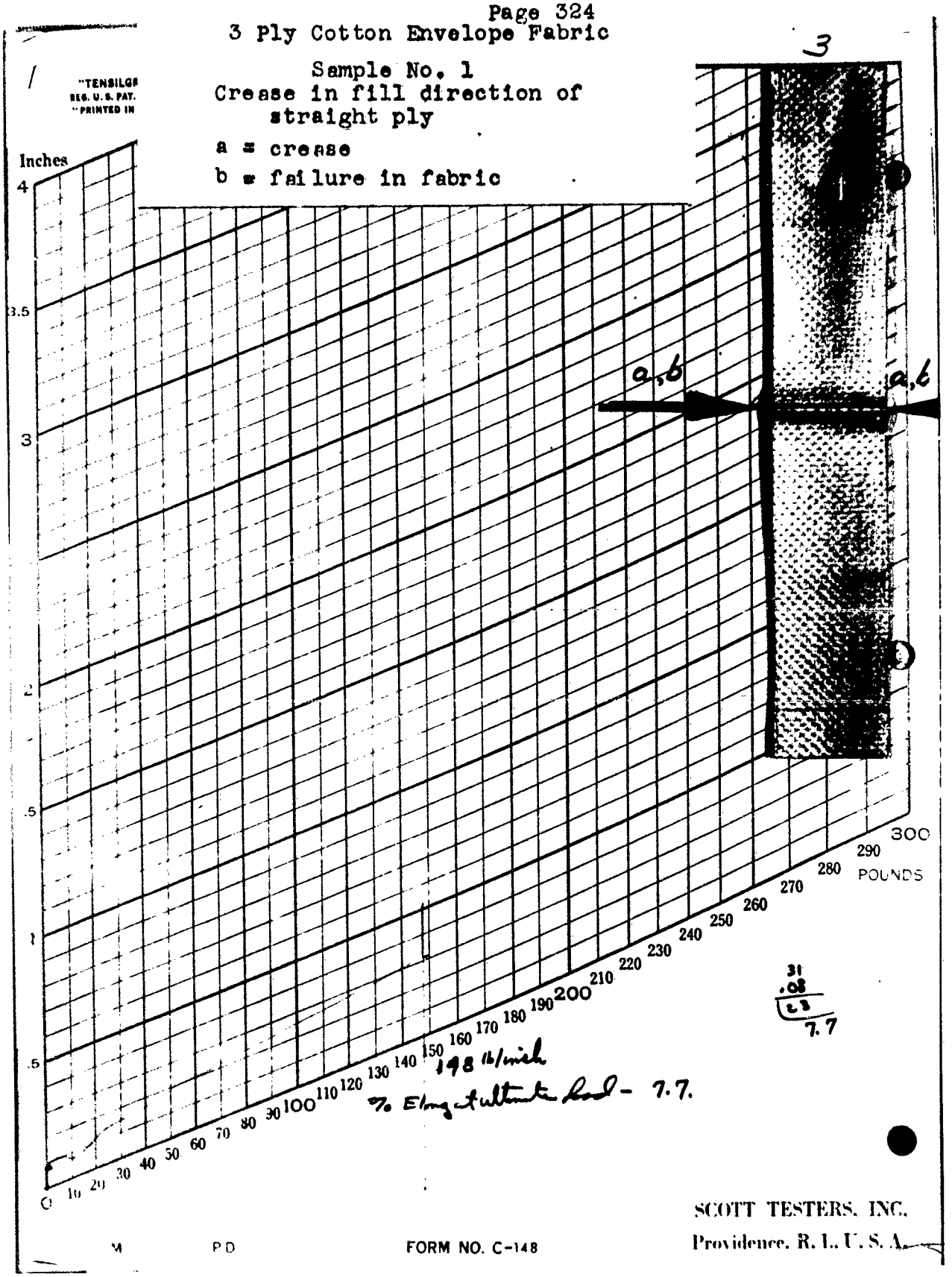


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Figure P8 R 50-3-1
Page 325

3 Ply Cotton Envelope Fabric

Sample No. 2
Crease in fill direction of straight ply

a = crease

b = failure in fabric

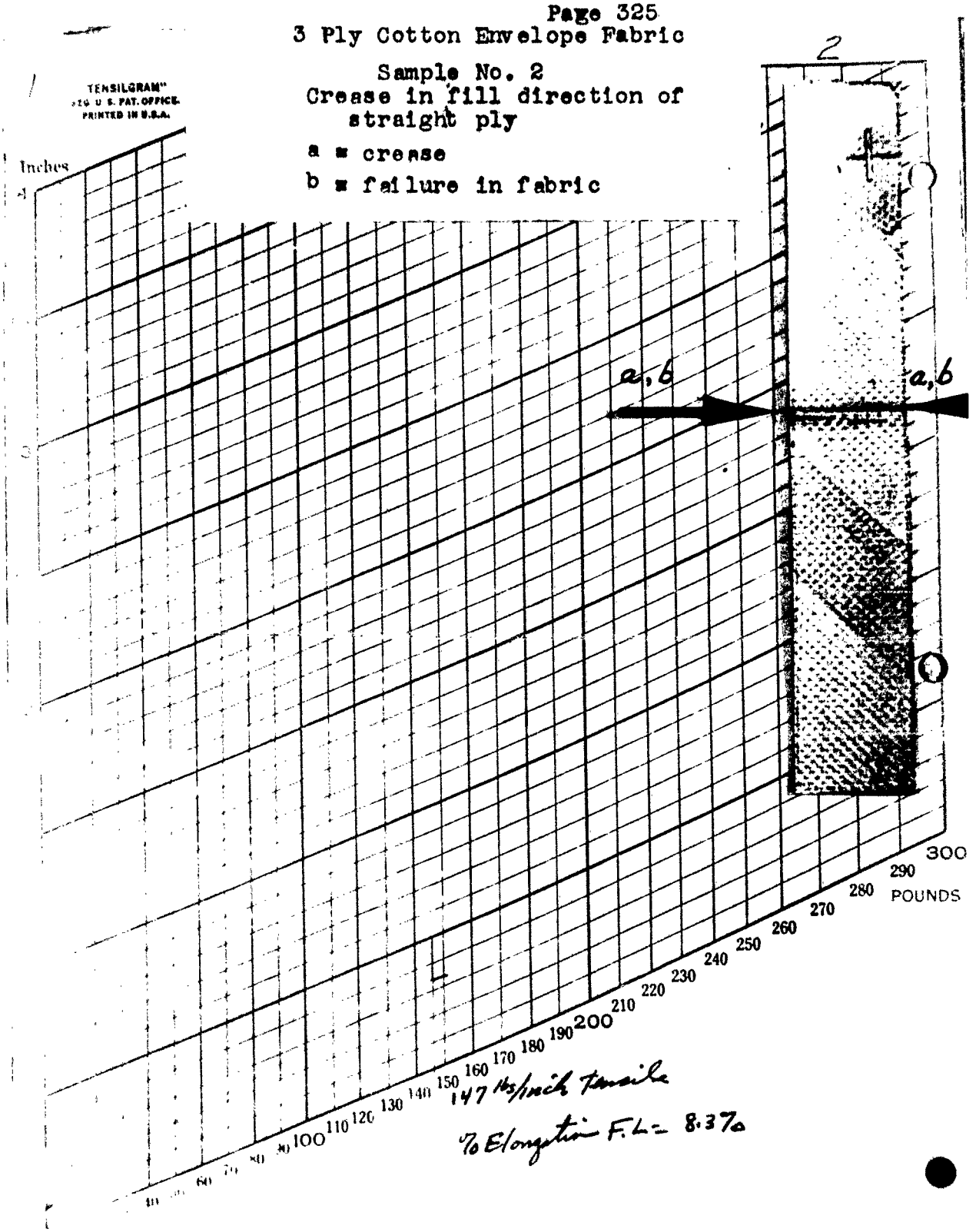

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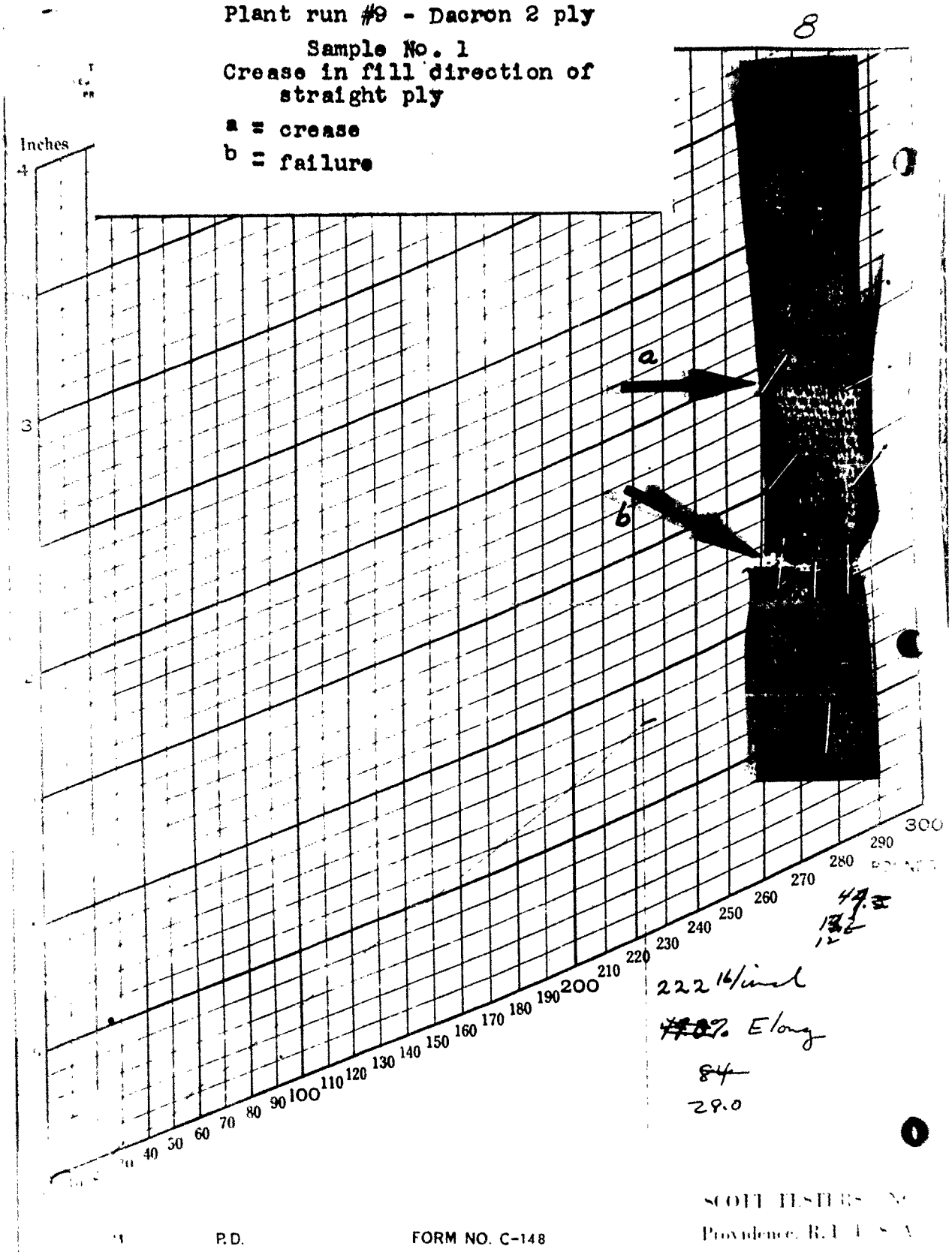
Figure P9

Plant run #9 - Dacron 2 ply

Sample No. 1
Crease in fill direction of straight ply

a = crease
b = failure



222 lb/inch
Elong
84
28.0

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Figure P10

R 50-3-1
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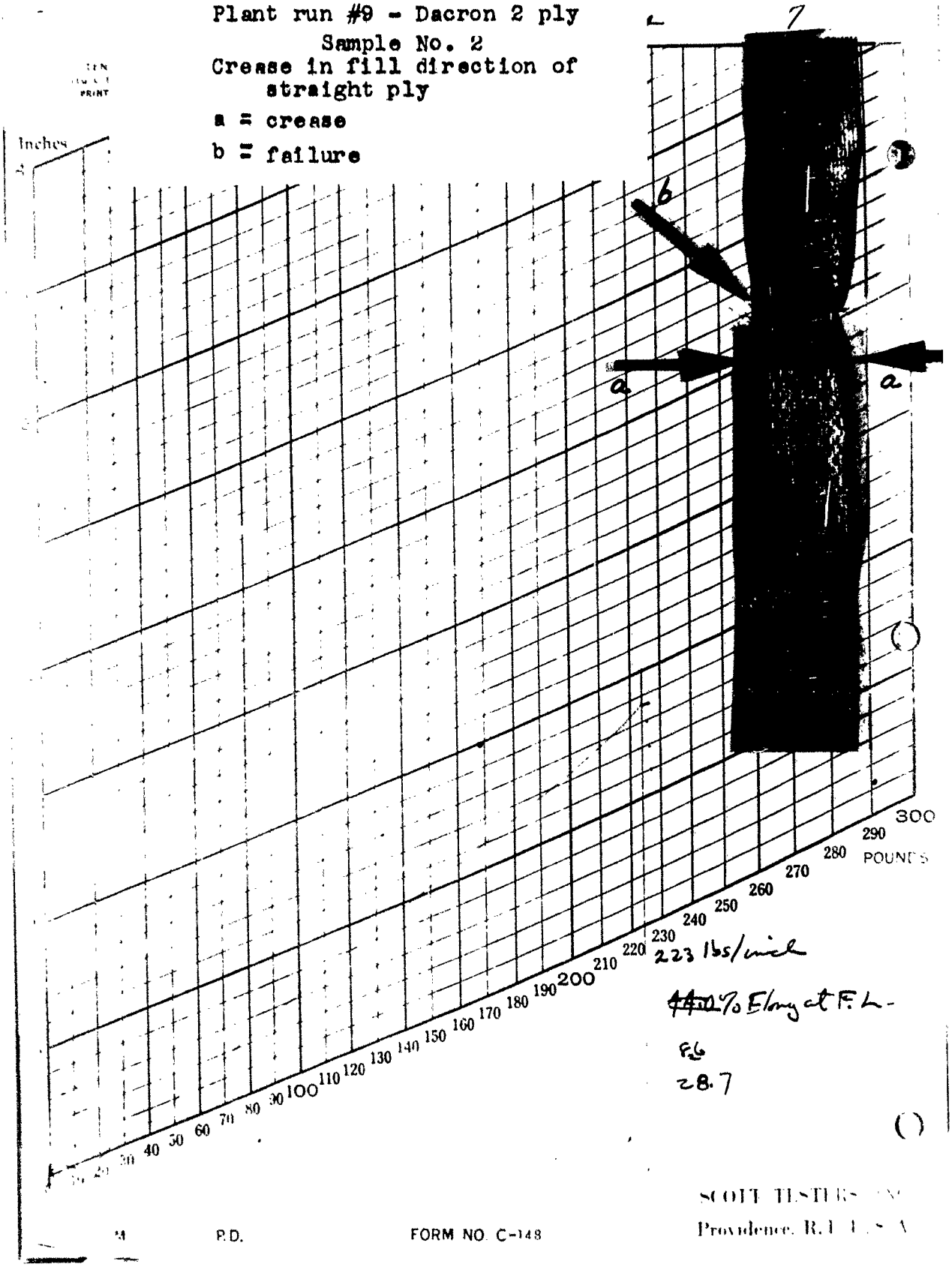
Plant run #9 - Dacron 2 ply
Sample No. 2
Crease in fill direction of straight ply
a = crease
b = failure



223 lbs/inch

~~44~~% Elong at F.L.

F.L.
28.7

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Figure P11 R 50-3-1
Page 328

Plant run #8 Nylon 2 ply

Sample No. 1
Crease in fill direction of straight ply

a = crease

b = failure

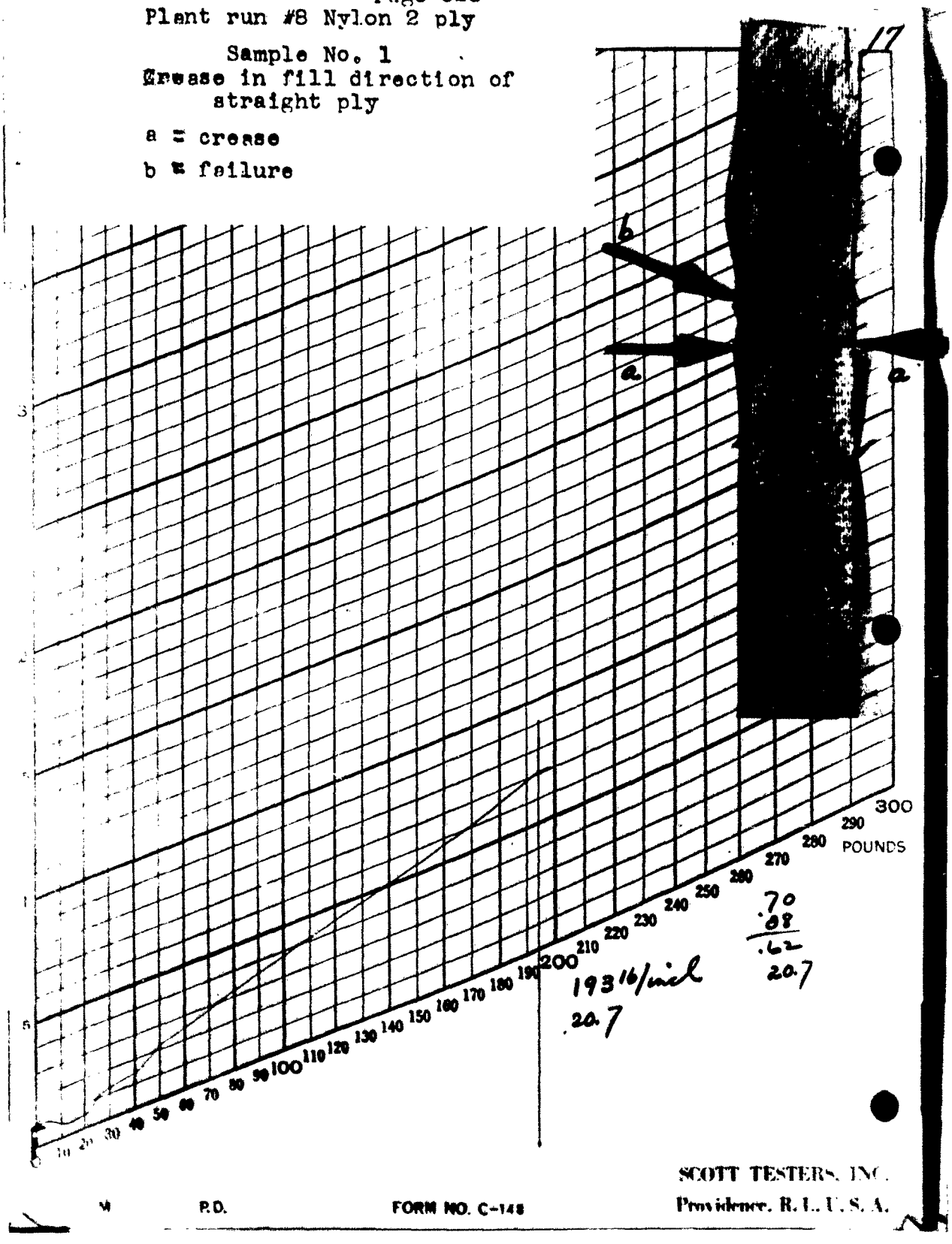

Figure P12 R 50-3-1
Page 329

Plant run #8 Nylon 2 ply

Sample No. 2
Crease in fill direction of straight ply

a = crease

b = failure

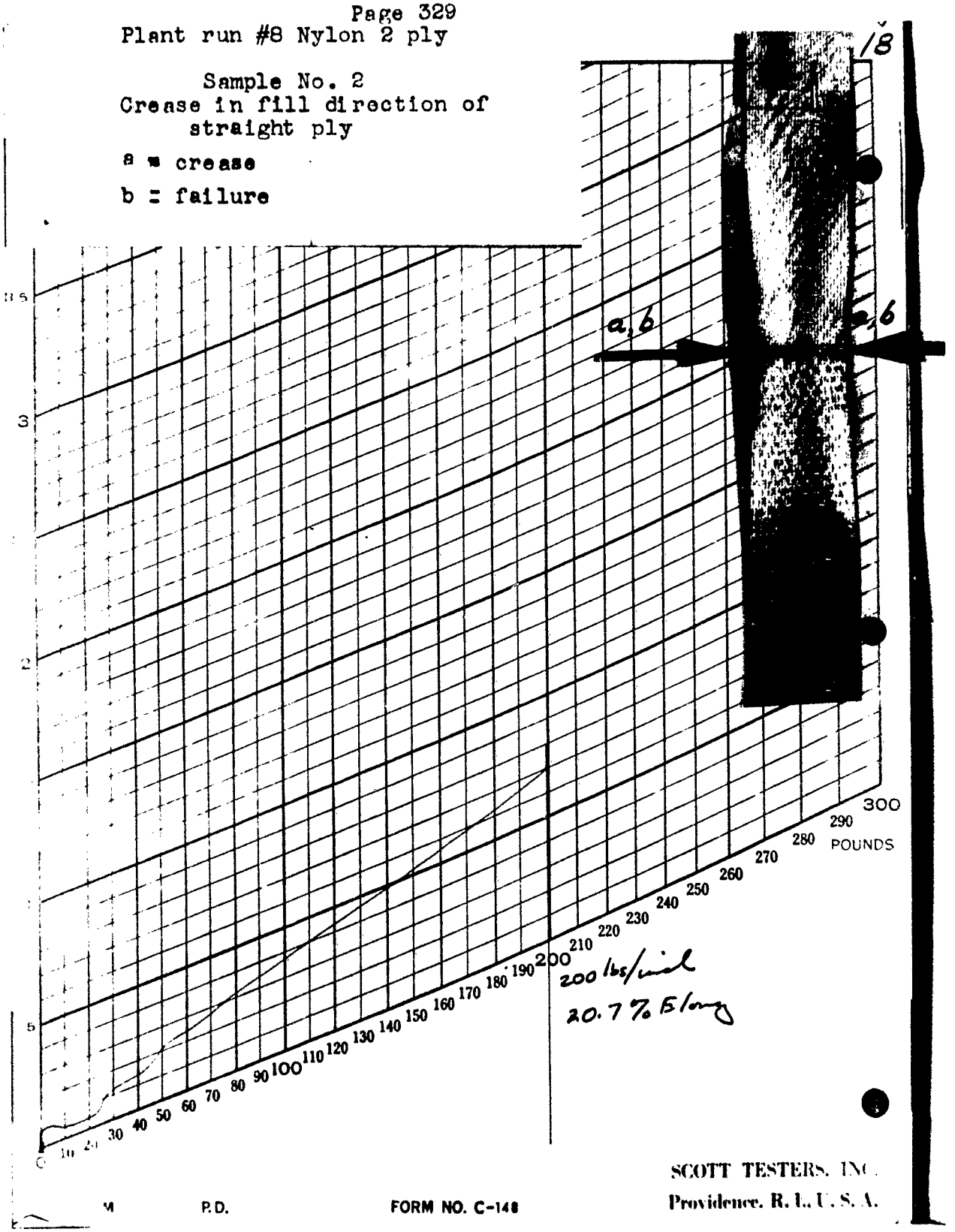

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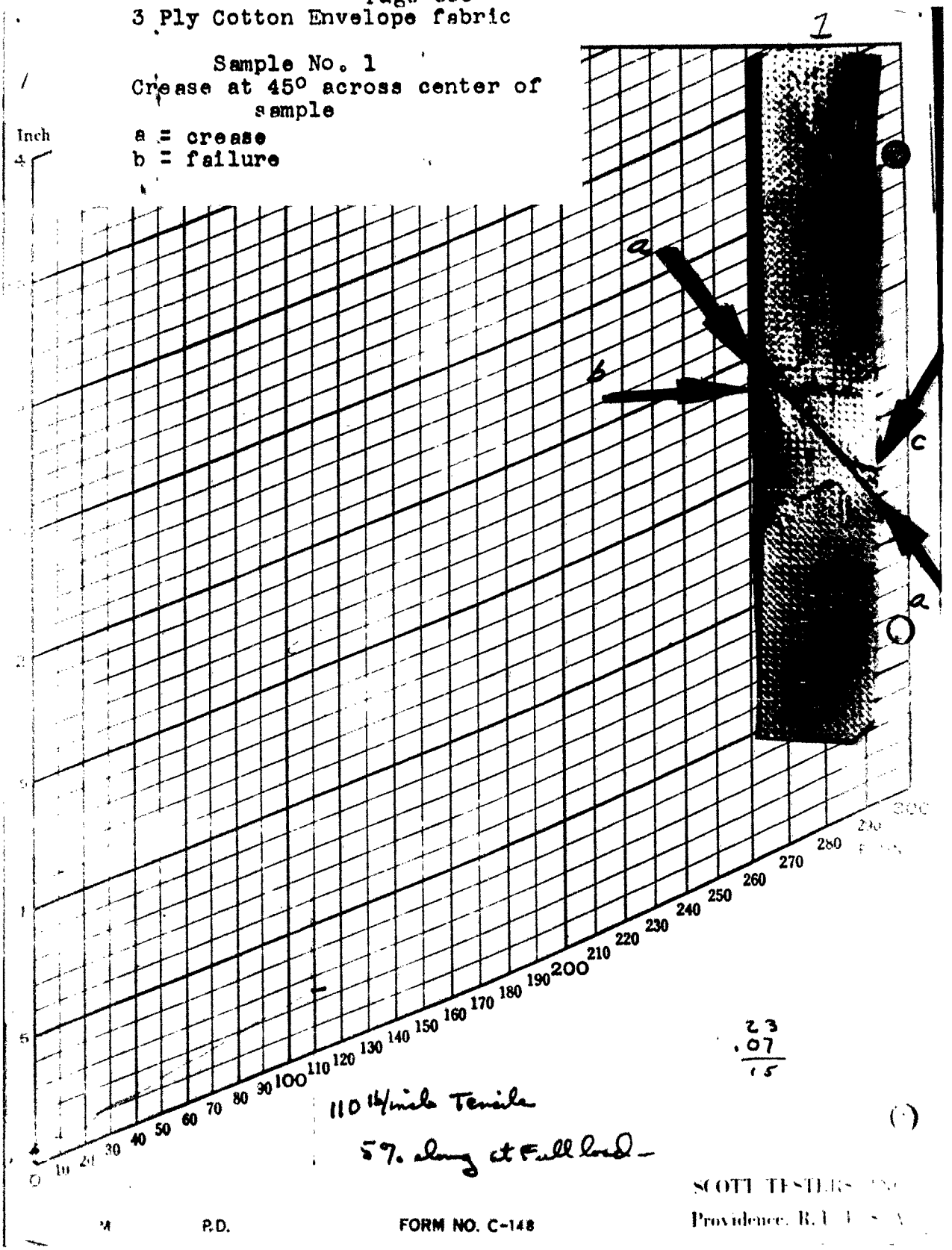
Figure P13 # 50-3-1
Page 330

3 Ply Cotton Envelope fabric

Sample No. 1
Crease at 45° across center of sample

a = crease
b = failure



1

23
.07
15

110 lb/inch Tensile

57. elong at Full load

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Figure P14 R 50-3-1
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3 Ply Cotton Envelope fabric

Sample No. 2
Crease at 45° across center of sample
a = crease
b = failure

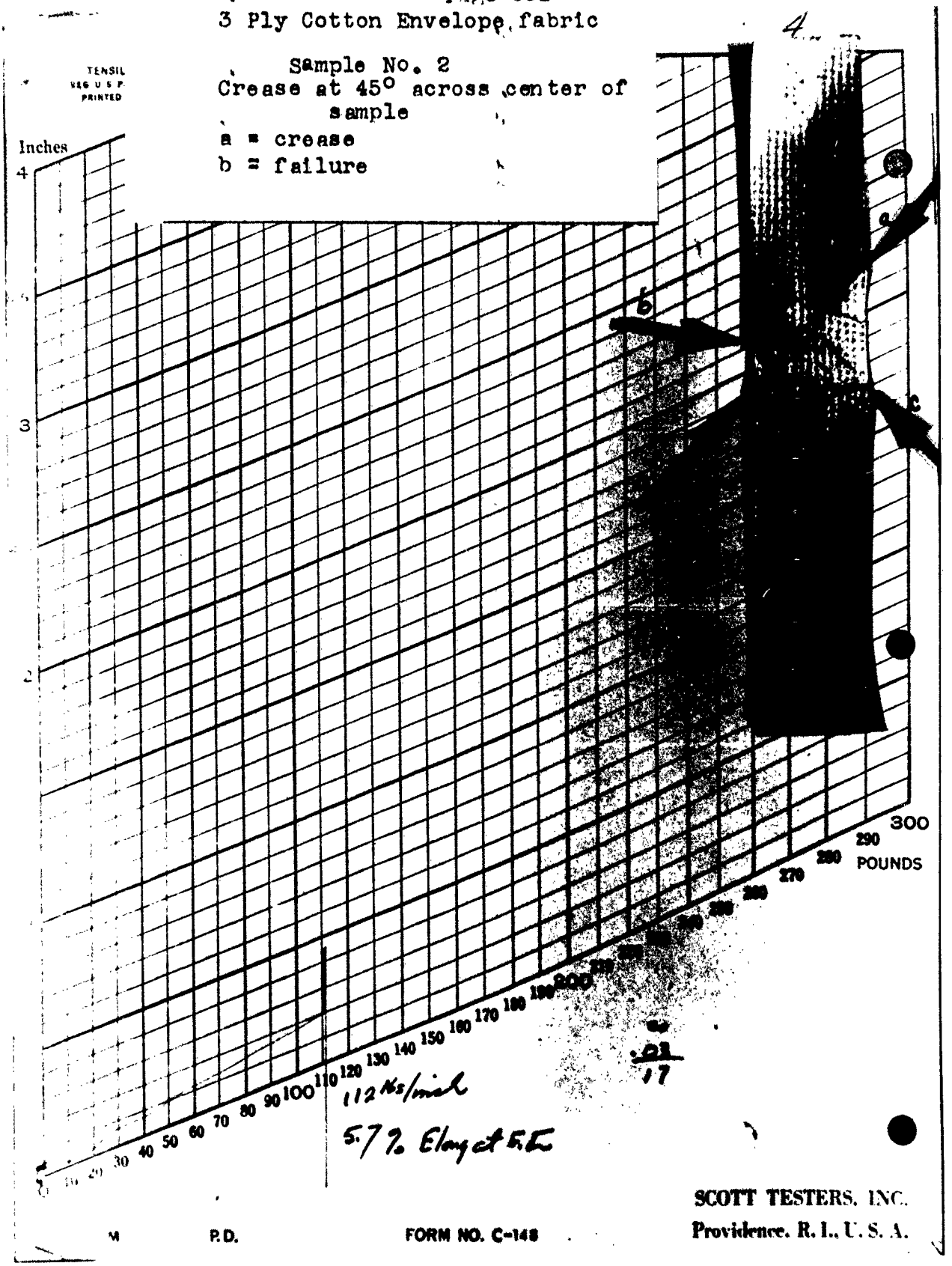

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Figure P15

50-3-1
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Plant run #9 Dacron 2- ply

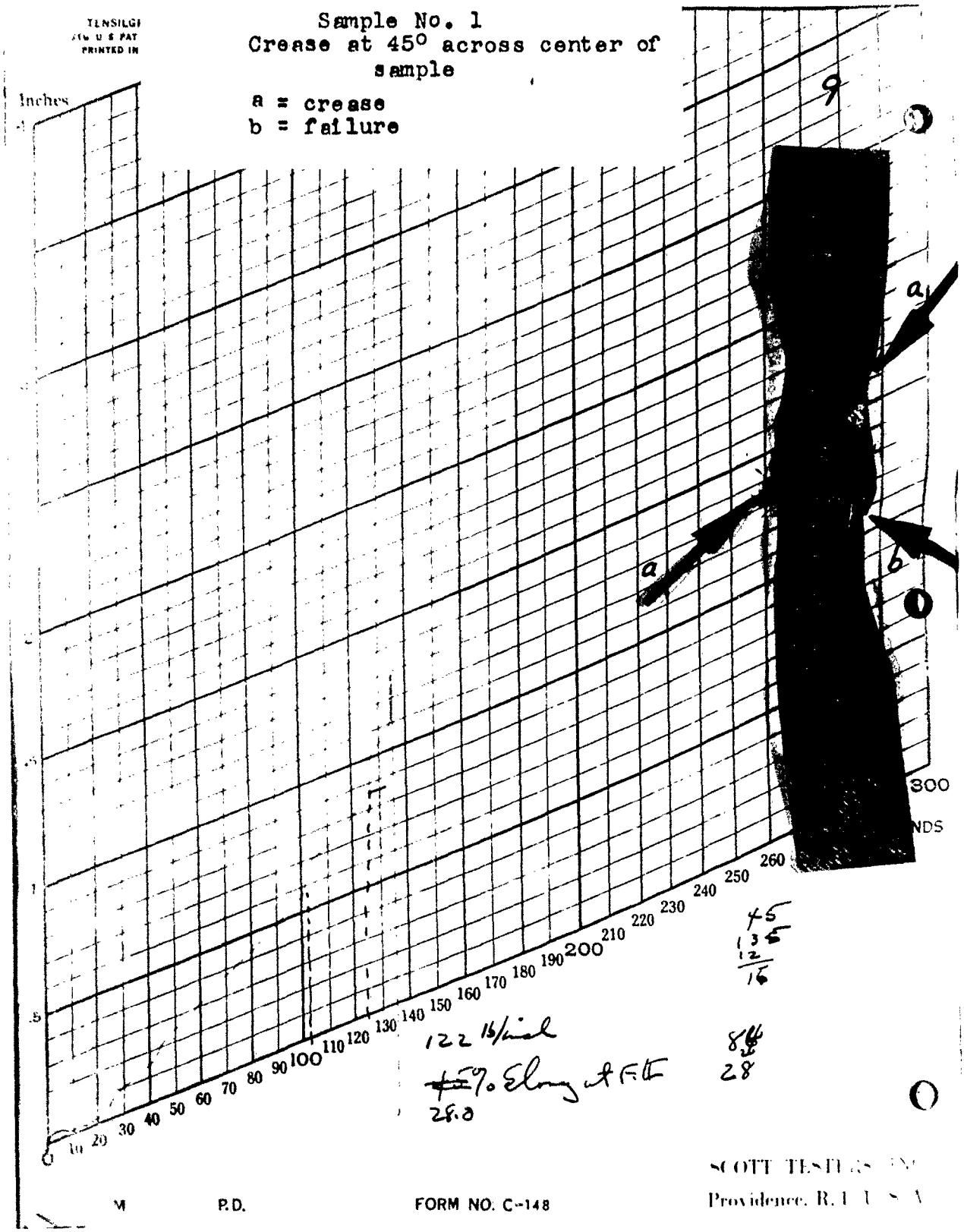

Figure P16

R 50-3-1
Page 333

Plant run #9 Dacron 2 ply

Sample No. 2
Crease at 45° across center of sample

a = crease
b = failure

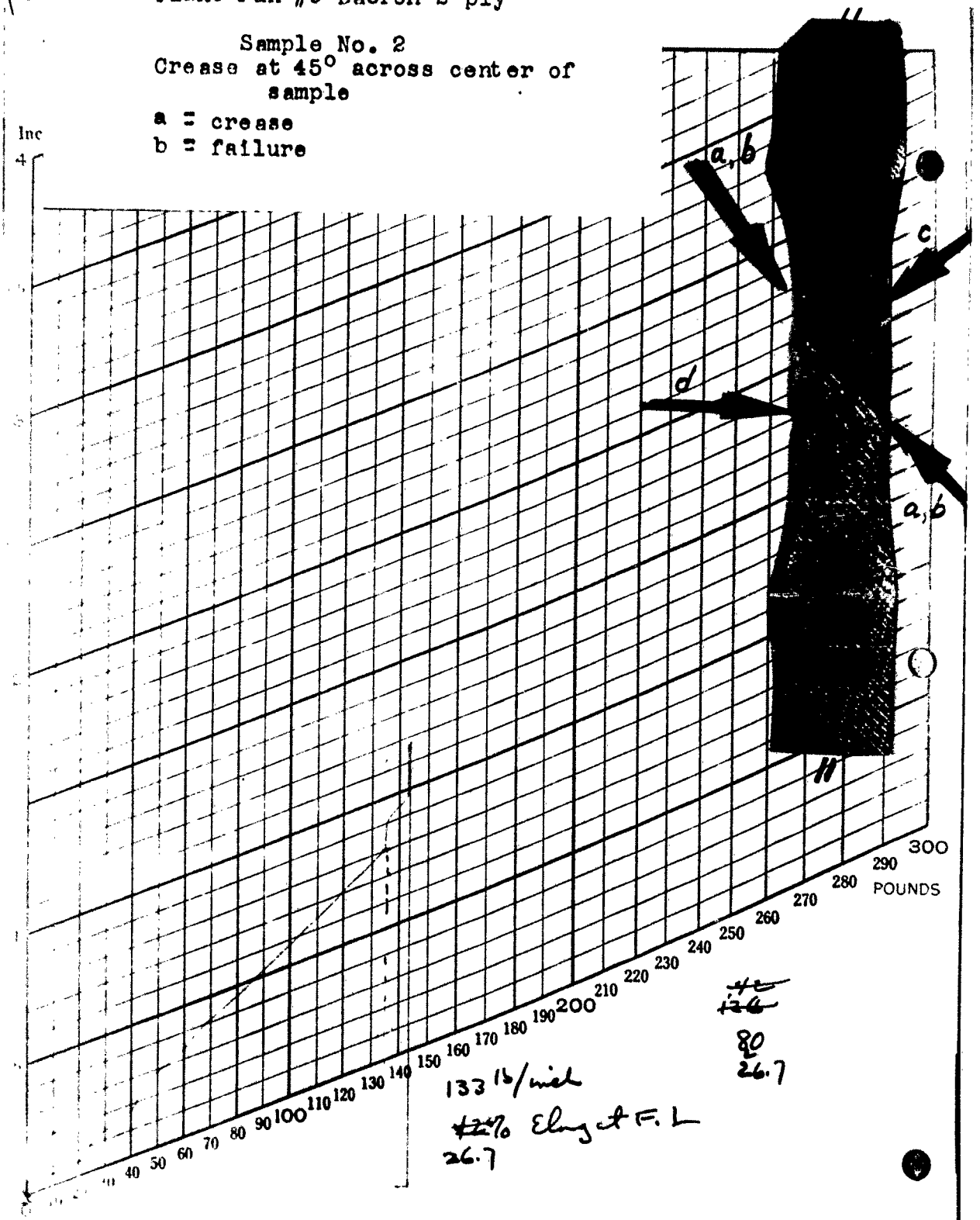

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Figure P17 R 50-3-1
Page 334

Plant run #8 Nylon 2 ply

Sample No. 1
Crease at 45° across center of sample

a = crease
b = failure

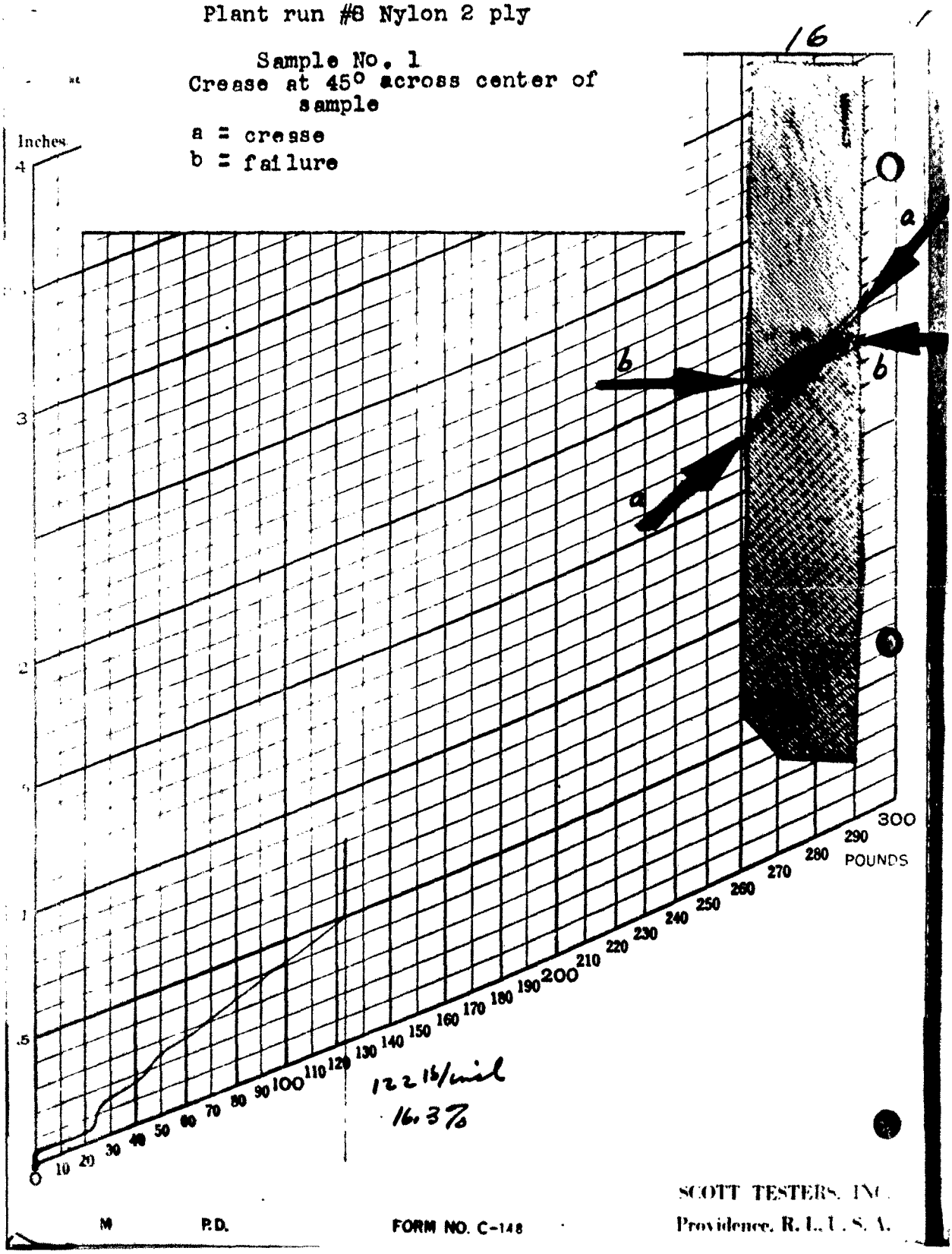

Figure P18

R 50-3-1
Page 335

Plant run #8 Nylon 2 ply

Sample No. 2
Crease at 45° across center of sample

a = crease
b = failure

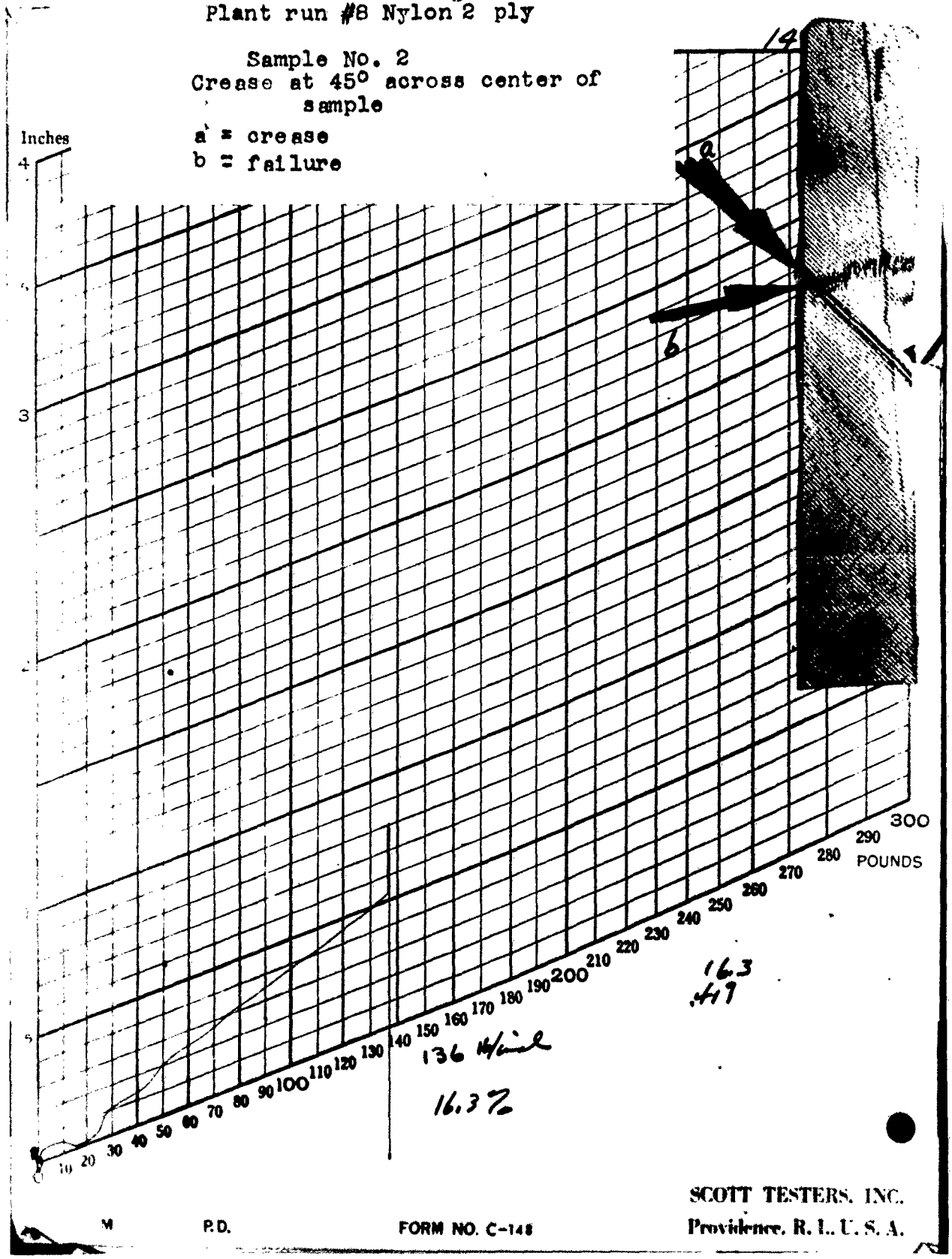

Figure P19 R 50-3-1
Page 336
Cotton 3 ply Envelope Fabric

Test specimen after cylinder burst test
(black arrows indicate seam)

Figure P20 R 50-3-1
Page 337
Plant Run #9 Dacron 2 ply

Test specimen after cylinder burst test
Warp direction
(black arrows indicate seam)

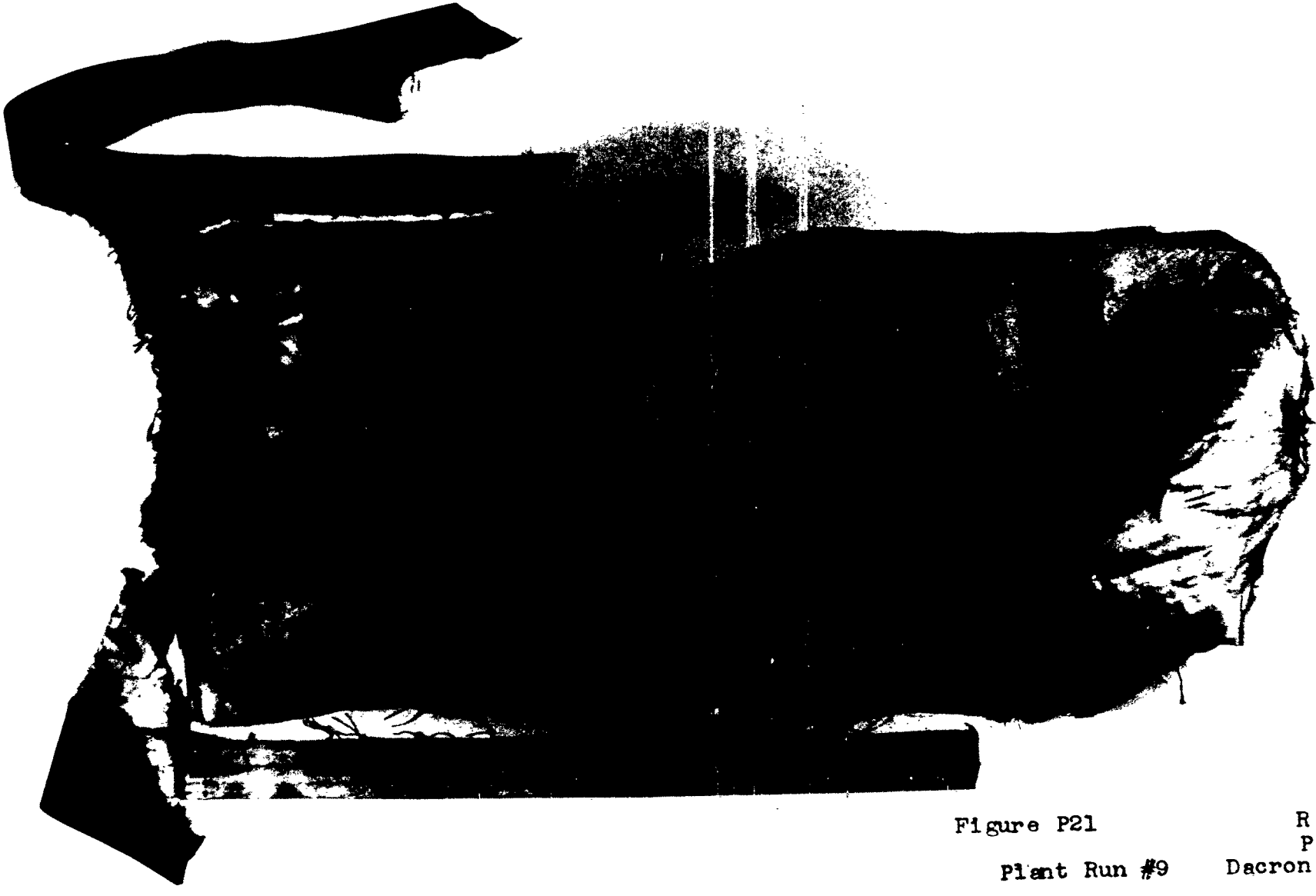

Figure P21

R 50-3-1
Page 338

Plant Run #9 Dacron 2 ply

Test specimen after cylinder burst test

Fill Direction
(black arrows indicate seam)

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APPENDIX II

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Burgess has analyzed the stresses in the fabric as follows:

"A fundamental formula may be derived to express the relations between the tensions in an element of fabric and the pressure upon it.

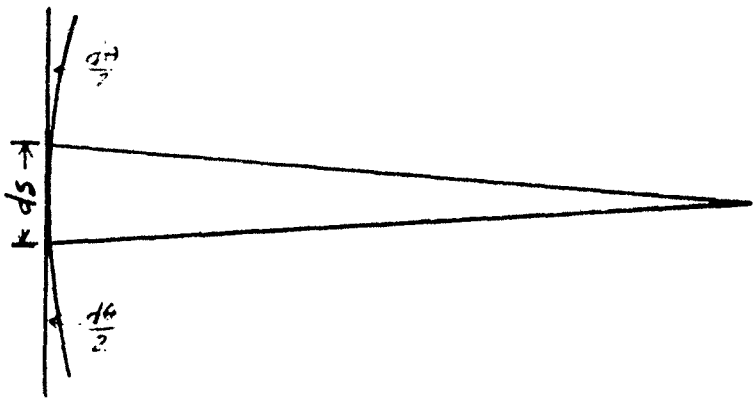

Fig. 35 Tension in a Wire

In Figure 35 let element ds of a fine wire subtend an angle dθ at its center of curvature. Since the element is short, its radius of curvature may be assumed constant irrespective of variations in the curvature of any considerable length of the wire. By geometry the tangents to the wire at the ends of the element make an angle equal to dθ/2 with the straight line through the ends of the element. If the wire sustains a transverse load p per unit length, equilibrium requires that this transverse force be opposed by the tension T in the wire, so that:

$$P\,ds = 2T \sin \frac{d\theta}{2}$$

Since the sine of a small angle equals the angle,

$$p\,ds = T\,d\theta \qquad (42)$$

and $$d\theta = \frac{ds}{R}$$ where R is the radius of curvature of the element ds.

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Therefore $$p = \frac{T}{R}$$

or $$T = Rp \qquad (43)$$

In a similar manner, the condition for equilibrium in the element of area of a fabric curved in two directions and with a transverse load of intensity, p, per unit of area, as shown in Figure 36, is that;

$$p\, ds_1\, ds_2 = 2T_1 \sin \frac{d\theta_1}{2}\, ds_2 + 2T_2 \sin \frac{d\theta_2}{2}\, ds_1$$

where T_1 and T_2 are the tensions in the two directions per unit width of fabric. As in the case of a transversely loaded wire this equation may be reduced to:

$$p = \frac{T_1}{R_1} + \frac{T_2}{R_2}$$

Or in the envelope of an airship:

$$p = \frac{T_t}{R_t} + \frac{T_l}{R_l} \qquad (44)$$

Where the subscripts t and l indicate that the tension or the radius of curvature is transversely or longitudinally as the case may be.

The equation (44) is in general indeterminate since it contains two unknowns. It becomes determinate when R_l is infinite because the last term is then zero, or when T_l is known. T_l may be calculated from the bending moment, the longitudinal forces, and the geometrical properties of the cross-section of the envelope at the point where the tensions in the fabric are desired. The longitudinal tension T_l may be regarded as consisting of two parts superimposed upon each other. The first is due to the total longitudinal force upon the envelope at the cross-section considered, and the second part is due to the bending moment at that section. The first part of T_l is equal to the total longitudinal force upon the envelope at the cross-section, divided by the perimeter of the cross-section, and the second part is obtained from the usual formula for the stress due to bending.

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A correction of about 5% to the stresses in the fabric may be made in most cases to allow for the increased strength derived from the overlapping of the seams. Corrections to allow for deformation of the envelope will be considered later.

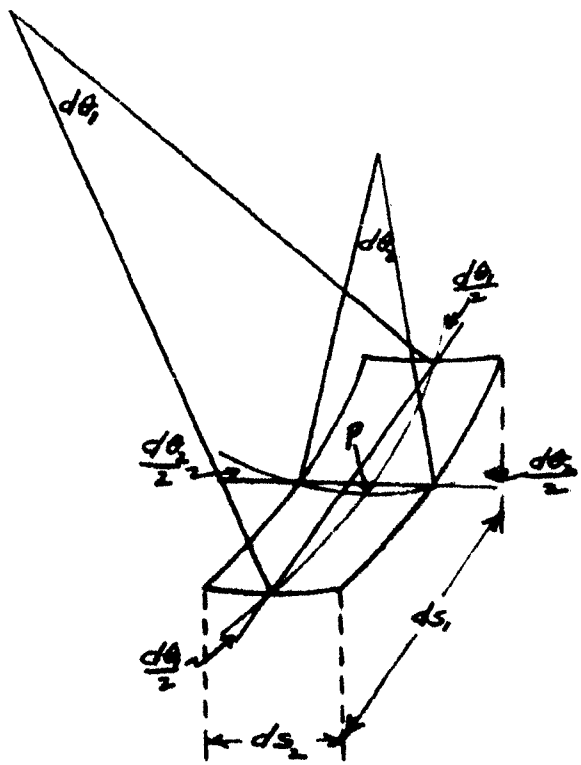

Fig. Tension in Fabric

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Where the longitudinal tangent to the envelope is inclined at an angle α to the longitudinal axis, a correction must be made for the difference between the actual tension in the fabric and the component of the tension parallel to the longitudinal axis. This component is found by neglecting α and T_l is equal to the component divided by $\cos.\alpha$.

The total longitudinal force upon a cross-section of the envelope is made up of the internal gas pressure, producing tension, and the longitudinal components of the tensions in the suspension cables producing compression. The total gas pressure force is equal to the area of the cross-section of the envelope multiplied by the mean gas pressure, i.e., the pressure at mid-height of the envelope. The compressive force due to the suspension cables may be found from the suspension diagram. The fact that the resultant of the longitudinal forces does not lie along the longitudinal axis of the envelope need not be considered, because the effect of the offset position of the resultant is included in the calculation of the bending moment.

In most problems dealing with the strength of fabric required in an airship envelope, R_l is so much greater than R_t that the last term in equation (44) may be neglected, and the formula for transverse tension in a cylinder or cone may be used:

$$T_t = pR_t$$

If R_l is neglected, the tapered portion of an envelope should be considered as consisting of a series of truncated cones. In that case, the transverse radius, R_t, at the point P, Figure 37, is the length of the line PQ drawn perpendicularly to the longitudinal tangent at P and intersecting the longitudinal axis at Q, and not the line PO which is the radius of the transverse section at P. The reason for this depends upon the theory of conic sections and need not be discussed here, except to note that R_t must obviously be determined in a plane which is perpendicular and not oblique to the surface at P.

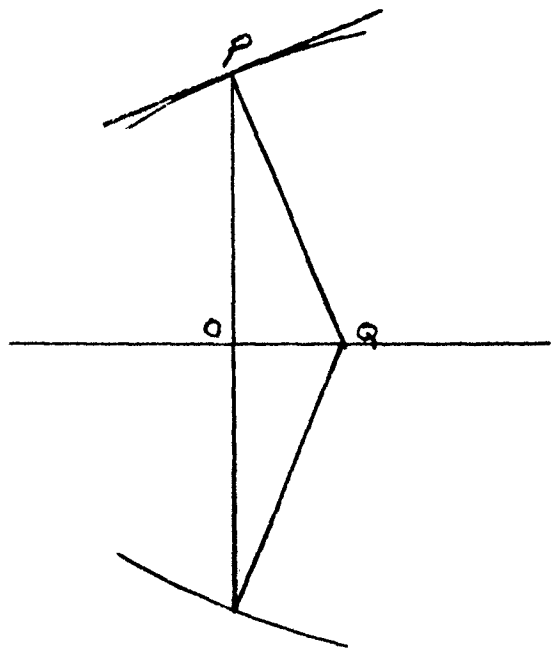

Fig. 37 Transverse Radius of Curvature in Conical Portion of an Airship

CALCULATION OF SHEARING STRESSES. In Figure 38 the small quadrilateral abcd having sides of the length dx and dy is subject to a shearing force of intensity f per unit of length along the sides ad and bc. These forces produce a couple (f dy dx) tending to produce clockwise rotation of the quadrilateral. Equilibrium requires that this couple be opposed by an equal and opposite one. If the shearing force on the sides ab and cd is also of intensity f, the couple on the quadrilateral will be (f dx dy) tending to produce anti-clockwise rotation. This is the couple required for equilibrium, and it follows that for equilibrium conditions, the intensity of the shearing stress at any point must be the same longitudinally as transversely. It is therefore permissible to

investigate the intensity of the shearing stress in an airship envelope by considering the shear either longitudinally or transversely.

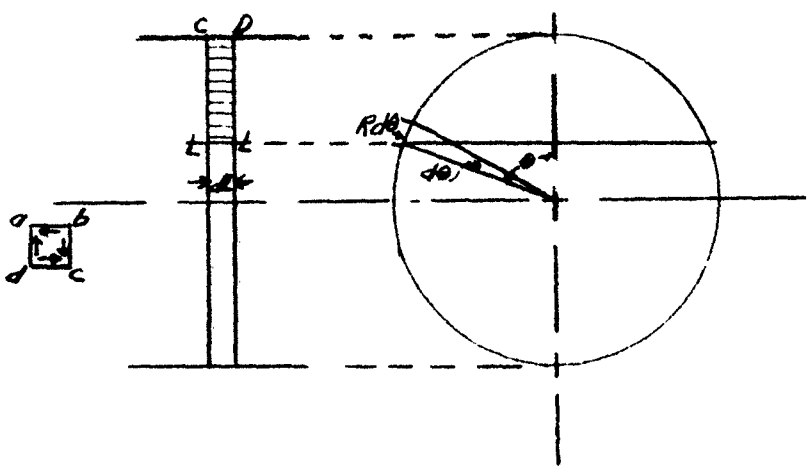

Figure 38 Longitudinal Shear in Nonrigid Airship

SHEAR LONGITUDINALLY. Let the total transverse shear force at the section CC in figure 38 be F, and let the shear per unit of length of the fabric be f. It is required to find the value of f at the intersection of the cross-section CC with the longitudinal section LL.

The total longitudinal stress in the fabric at CC between LL and the top of the cross-section due to the bending moment is in accordance with the theory of bending equal to:

$$\frac{M}{I} \int_0^{\theta} v \, R \, d\theta$$

But $y = R \cos \theta$

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Therefore the integral is $\frac{MR^2}{I}\int_0^{\theta} \cos\theta\, d\theta$

$$= \frac{MR^2}{I} \sin\theta$$

Similarly the total longitudinal stress in the fabric between LL and the top of the cross-section DD at an indefinitely small distance dl from CC is equal to:

$$\frac{(M - dM)R^2}{I} \sin\theta$$

where dM is the change of the bending moment between CC and DD. By the theory of shearing forces and bending moments, the change of bending moment between two cross-sections equals the integration of the shear between those sections; therefore, $dM = F\, dl$.

The difference of the total longitudinal forces at CC and DD between LL and the top of the envelope is equal to:

$$\frac{R^2 \sin\theta\, dM}{I} = \frac{R^2 \sin\theta}{I} F\, dl$$

This difference of the longitudinal forces at CC and DD must obviously equal the total shear along LL between CC and DD. It follows that:

$$f\, dl = \frac{R^2}{I} \sin\theta\, F\, dl$$

In a circular cross-section $I = \pi R^3$

Therefore
$$f = \frac{F \sin\theta}{R\pi} \qquad (46)$$

SHEAR TRANSVERSELY. Equation (46) may also be obtained by considering the shear transversely in Figure 39. Suppose that the section DD moves downward relatively to CC a small distance dy. This movement has a tangential component dy sin θ at LL, and a radial component dy cos θ. The radial component has no effect upon the stresses in the fabric, but the tangential component produces shearing strains and stresses.

The shearing stress is proportional to dy sin Θ, and it follows that if f_m is the maximum intensity of the shearing stress on the cross-section CC, the intensity of shear at any point on CC is given by:

$$f = f_m \sin \Theta$$

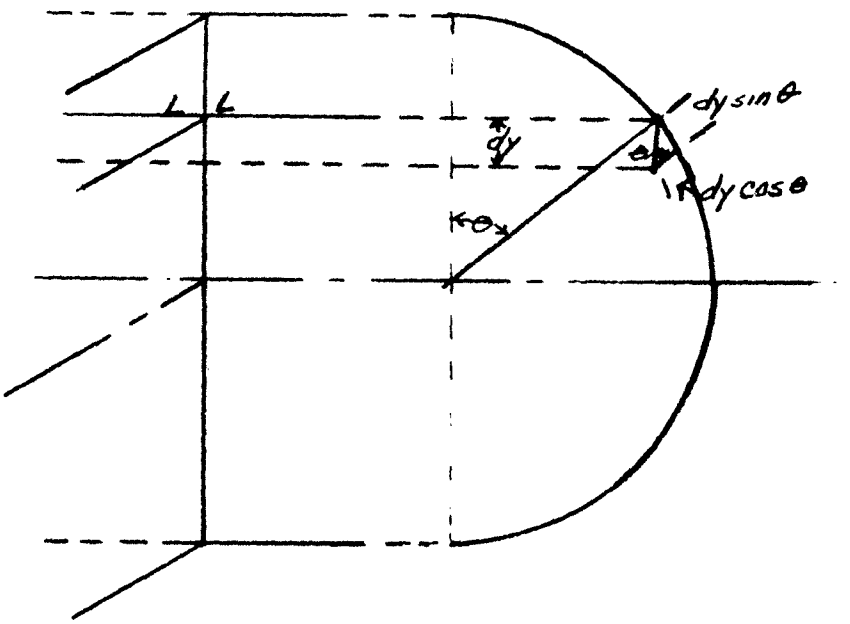

Fig. 39 Transverse Shear in a Nonrigid Airship

The vertical component of the shearing stress is f sin Θ, and the total vertical shearing force must equal the integration of the vertical components over the whole cross-section. Therefore:

$$F = \int_0^{2\pi} f \sin \Theta \, R \, d\Theta$$

$$= Rf_m \int_0^{2\pi} \sin^2 \Theta \, d\Theta$$

$$= R f_m \pi \qquad (47)$$

or $$f_m = \frac{F}{R\pi}$$

and $$f = \frac{F \sin \theta}{R\pi} \qquad (46a)$$

This is the same result as was obtained by considering the shear longitudinally; but this agreement is found to exist only when the cross-section is circular, which indicates that the ordinary bending moment formula is strictly applicable only for circular cross-sections. That is to say, when the cross-section is other than circular, bending produces a distortion of the cross-section so that the Navier hypothesis is not precisely fulfilled.

If a cross-section on a conical portion of the envelope is considered, the tangential component of the shear still equals dy sin θ, and the integration of the shearing stresses also remains unchanged, so that the value of f is the same as in a cylinder. The only difference between the cone and the cylinder is that to a distance dl parallel to the longitudinal axis of the envelope corresponds a breadth of fabric equal to dl/cos α, instead of equal to dl, where α is the inclination of LL to the longitudinal axis. A given shearing force produces, therefore, a greater value of the displacement dy in the ratio of I: cos α for the cone as compared with the cylinder.

ELLIPSE OF STRESS. The methods of finding the intensity of the tension and shear in the fabric longitudinally and transversely at any point in the envelope have been investigated in the preceding sections. The maximum intensity of the stress may not, however, lie in either of these directions, and it is often desirable to know the direction and magnitude of the maximum and minimum tensions. This problem is especially liable to occur in the design of reinforcements for the envelope, such as trajectory bands. The magnitude of the tension and shear in any direction may be determined by a geometrical analysis known as "the ellipse of stress."

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In Figure 40 let OX and OY be two perpendicular coordinate axes. In an elementary rectangular area of fabric, ABCD, having sides parallel to these axes, let the tensions parallel to OX and OY per unit width of fabric be T_x and T_y, respectively. Let the shear be zero in the directions of OX and OY. In the

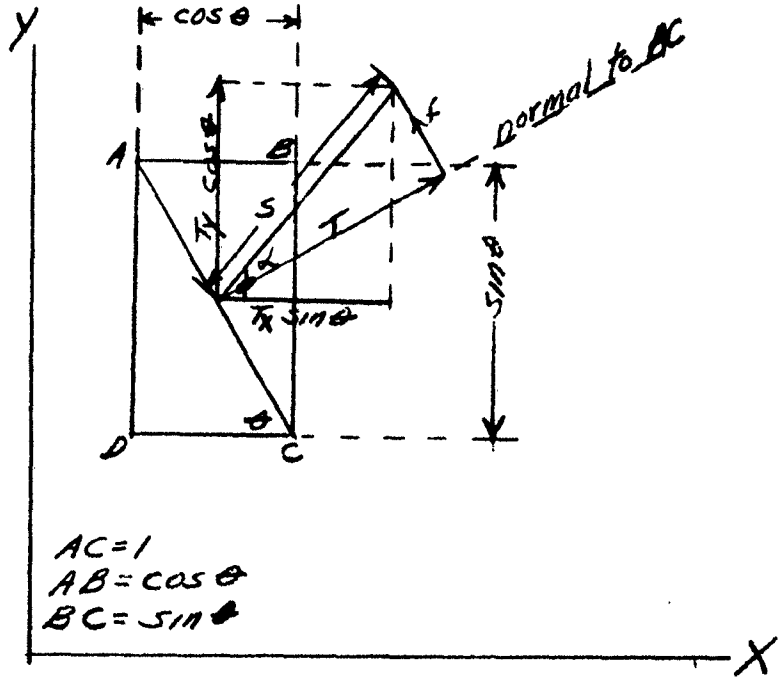

Figure 40. Principal Stresses in a Nonrigid Airship Envelope

elementary rectangle ABCD, let the diagonal AC be inclined to OX at an angle θ, and let the length of AC be unity. Then the forces upon AC due to the unit tensions T_x and T_y are $T_x \sin \theta$ and $T_y \cos \theta$, respectively. Let the resultant of these two forces be S, inclined to OX at the angle Ø. Then from the resolution of forces, Figure 40,

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$$S \cos\phi = T_x \sin\theta$$

and $$S \sin\phi = T_y \cos\theta$$

Whence $$\frac{S^2 \cos^2\phi}{T_x^2} = \sin^2\theta$$

and $$\frac{S^2 \sin^2\phi}{T_y^2} = \cos^2\theta$$

But $$\sin^2\theta + \cos^2\theta = I$$

Therefore $$\frac{S^2 \cos^2\phi}{T_x^2} + \frac{S^2 \sin^2\phi}{T_y^2} = I$$

This is the equation of an ellipse in which S is the radius vector, and T_x and T_y are the axes.

The resultant stress S upon any line of unit length may be resolved into two components, a tension T normal to the line, and a shear f parallel to the line. In Figure 40 let α be the angle between the normal to Ac and the direction of S. Then:

$$\alpha = \theta + \phi - 90^\circ$$

Also $$T = S \cos\alpha$$

and $$f = S \sin\alpha$$

From Figure 40, $$\tan\phi = \frac{T_y \cos\theta}{T_x \sin\theta}$$

Only in the directions of the axes of the ellipse of stress is the resultant stress a pure tension without shear, for $\alpha = 0$ only when the stress is considered upon a line parallel to one of these axes.

In the preceding investigation it was assumed that the directions of the axes of the ellipse were known; but in actual problems dealing with airship envelopes, the more general case is when the longitudinal and transverse tension and shear stresses are known, but not the directions of the

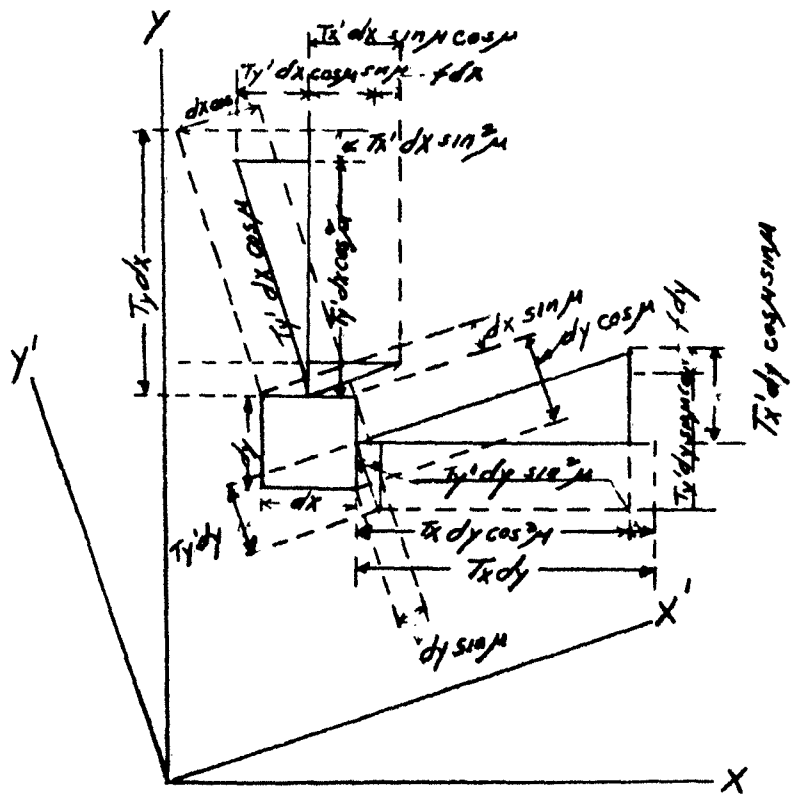

Figure 41. Tension and Shear in Any Direction

axes of the ellipse of stress. The effect of the shear in the longitudinal and transverse directions is to rotate the axes of the ellipse to the directions in which there is no shear. The new axes give the direction and magnitude of the maximum and minimum tensions in the fabric at the point considered.

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Suppose that the unit tensions T_x and T_y and the unit shear stress f parallel to the coordinate axes OX and OY in Figure 41 are known. Let the axes of the ellipse of stress by OX' and OY' inclined at the angle μ to OX and OY, respectively. The tensions parallel to OX' and OY' have components in the directions of OX and OY equal to the known tensions and the shear in those directions. Let the tensions parallel to OX' and OY' be $T_{x'}$ and $T_{y'}$, respectively. By equating the components of $T_{x'}$ and $T_{y'}$ in the directions of OX and OY to the values of T_x and T_y, the relations are obtained (Figure 41):

$$T_x dy = T_{x'}\, dy \cos^2\mu + T_{y'}\, dy \sin^2\mu$$

and

$$T_y dx = T_{y'}\, dx \cos^2\mu + T_{x'}\, dx \sin^2\mu$$

These equations reduce to:

$$T_x = T_{x'} \cos^2\mu + T_{y'} \sin^2\mu \qquad (48)$$

$$T_y = T_{y'} \cos^2\mu + T_{x'} \sin^2\mu \qquad (49)$$

The shearing force is connected to the tensions by the equation:

$$f\, dy = - T_{x'}\, dy \cos\mu \sin\mu + T_{y'} dy \sin\mu \cos\mu$$

or

$$f = (T_{y'} - T_{x'}) \sin\mu \cos\mu \qquad (50)$$

The unknown, $T_{x'}$, $T_{y'}$, and μ may be determined from equations (48), (49), and (50).

By substituting $1 - \sin^2\mu$ for $\cos^2\mu$ in equation (48):

$$\sin^2\mu = \frac{T_x - T_{x'}}{T_{y'} - T_{x'}} \qquad (51)$$

By the same substitution in (49):

$$\sin^2\mu = \frac{T_{y'} - T_y}{T_{y'} - T_{x'}} \qquad (52)$$

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From (51) and (52):

$$T_x + T_y = T_x' + T_y' \qquad (53)$$

From (50) and (51):

$$f^2 = (T_y' - T_x')^2 \left[\frac{T_x - T_x'}{T_y' - T_x'} - \left(\frac{T_x - T_x'}{T_y - T_x'} \right)^2 \right] =$$

$$(T_x - T_x')\ (T_y' - T_x)$$

Substituting the value of T_y' from (53):

$$f^2 = T_x'^2 - (T_x + T_y)\ T_x' + T_x\ T_y$$

or substituting or T_x'

$$f^2 = T_y'^2 - (T_x + T_y)\ T_y' + T_x\ T_y$$

From these two equations:

$$T_x' \text{ or } T_y' = \frac{T_x + T_y \pm \sqrt{(T_x + T_y)^2 - 4\ T_x T_y + 4f^2}}{2} \qquad (54)$$

The two roots of this quadratic are the values of T_x' and T_y'.

CRITICAL SHEAR. Since fabric is incapable of sustaining compression, folds will begin to appear in the envelope whenever the tension in any direction falls below zero. It may be seen from the last example that when a shearing stress is added to known values of T_x and T_y, the effect is to rotate the axes of the ellipse of stress and to change their relative lengths. Clearly, if folds in the fabric are to be avoided, a limiting value of the shear stress is when the length of one axis is zero. This will occur when the quantities outside of and under the square root sign in equation (54) are equal, i.e., when

$$T_x + T_y = \sqrt{(T_x + T_y)^2 - 4\ T_x\ T_y + 4f^2}$$

Solving this equation:

$$f = \sqrt{T_x\ T_y} \qquad (55)$$

which is the limiting or critical value of f."

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APPENDIX III

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